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Abstract

This paper examines the effect of financialisation of futures markets has on the relationship between crude oil futures and equities by using the VAR-DCC-GARCH model. Specifically, by accounting for the systematic patterns of commodity price volatility, namely, seasonality and maturity effects for the pre-financialisation (1993-2003) and post-financialisation (2004-2019) period. While speculation that reflects non-commercial investors' activity is found to have a negative impact on crude oil futures' volatility before the financialisation period, open interest as a measure of liquidity has a negative effect after 2004. The finding indicates weakening seasonality in crude oil futures and diminishing Samuelson maturity effect i.e. volatility of the contract increases as it nears to expiration since financialisation. This confirms the importance of accounting for volatility dynamics while contributing to financialisation debate.

JEL-Codes: C320, G120, G150.

Keywords: financialisation, volatility dynamics, Samuelson hypothesis, correlation, seasonality.

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In this paper, we use the term "pre"/"before" financialisation for the period dated before 2004 and "post"/"during"/"after"/"since" financialisation for the period beginning of 2004. Further details on choosing sample period are described in Section 4.1.2.

1. Introduction

Since the enactment of the Commodity Futures Modernization Act (CFMA) of 2000, many commodity markets have experienced an unprecedented increase in their trading volume and positions held by non-commercial investors (Frenk 2010; CFTC 2008).[2] This considerable increase could be because the act supported the growth of "financial entrepreneurship" by exempting hedge fund activity and energy derivative trading from regulation. It could have also reduced the cost of futures trading for specific groups of investors such as hedge funds, mutual funds, banks and insurance companies (Basher and Sadorsky 2016). Moreover, this Act has weakened speculative position limits and created other loopholes for speculators (Frenk 2010).[3] Concurrently, the level and volatility of energy and agricultural commodity prices increased sharply although there was a significant fall during the Global Financial Crisis (GFC) (Domanski and Heath 2007; Dwyer, Gardner, and Williams 2011). Moreover, there has been an increase in co-movement across commodities and between equities and commodities. Figure 1 illustrates a consequence of these changes depicting, open interest held by commercial and non-commercial traders in the crude oil futures market, over the period between 1993 and 2019. This rapid increase (particularly since 2004) in the trading volume and positions held by financial investors in commodity markets is often referred to as financialisation of commodities. In general, theory suggests that an increase in the trading volume contributes to price discovery process. However, the increase in trading volume in the commodity futures market raises a highly debated question in the empirical literature on the possible cause of observed changes in price, volatility, degree of co-movements between commodities and equities, and whether these changes relates to economic fundamental factors and business cycle (Fattouh, Kilian, and Mahadeva 2013; James D. Hamilton 2009b; Kilian and Murphy 2014) or financial innovation (i.e. creation of derivatives) in the commodity futures market (Masters 2008; K. Tang and Xiong 2012).

Our study contributes to the consideration of the impact of financialisation and presents evidence on whether financialisation has altered the nature of the commodity futures market and increased the connectedness between equities and commodities. This involves exploring the return volatility of commodity futures and equities; and their volatility linkage. As commodity price exhibits unique volatility patterns (clustering effect, seasonality, Samuelson volatility and correlation effect), we also focus on the systematic patterns of price volatility of commodities and how this is impacted by the financialisation.[4]

One of the rationales for examining the volatility dynamics is that, if the Samuelson hypothesis holds, it is

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[2] Non-commercial investors are the market participants/financial investors who use futures markets to speculate for portfolio diversification. They are also referred to as speculators.

[3] For example, a. *the Enron loophole* - exemption of electronic trading of energy derivative; which was formally closed through legislation in the Agricultural Act of 2014 (also known as 2014 U.S. Farm Bill); b. *London loopholes*- trading of energy futures contracts on Intercontinental Exchange (ICE) in London and on NYMEX in New York at the same time (UNCTAD 2009b). This loophole allows the opportunity to trade outside the regulatory jurisdiction of the Commodity Futures Trading Commission (CFTC); and c. *Swap-dealer loophole*- swap transactions into the over-the-counter (OTC) markets from exchanges; allowing no necessary requirement of dealing with regulators, exchanges or clearing house (UNCTAD 2009c); which has increased institutional investors in the commodity markets. In accordance with common literature, we use non-commercial investors as the speculators who use derivatives markets to speculate on the direction of futures price movement and commercial investors as the hedgers in derivatives markets to hedge price risk in this paper. However, it should be acknowledged that in some cases, hedgers also enter the futures market to speculate or to seek arbitrage.

[4] Samuelson (1965) in his seminal paper shows that the volatility of futures price increases as the time to contract expiration nears.

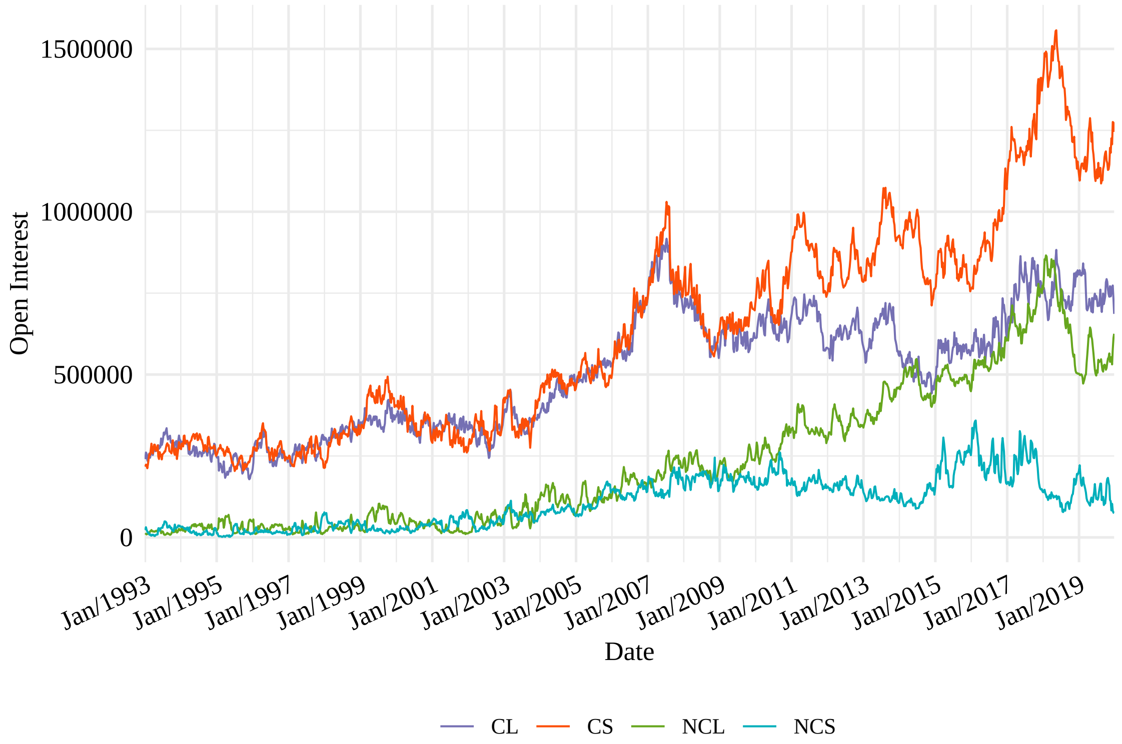

Figure 1: The evolution of open interest. NCL, NCS, CL and CS represents non-commercial long position, non-commercial short position, commercial long position and commercial short position respectively.

required that the estimates of volatility rely on remaining time till the underlying contract matures to get an accurate valuation of a derivatives instrument (Bessembinder and Seguin 1993). Moreover, by observing intra-and inter-seasonal price movement, both producers and investors can make next season's optimal production level and investment decision and therefore, can minimise seasonal price variability (UNCTAD 2009b, 24).[5] Thus, ignoring these systematic volatility patterns could lead to overestimate the volatility (price and return) and cross-market linkage (in return and volatility) between commodity futures and equity, and overestimate the role of financialisation.

To address the above research questions, we consider crude oil futures as representative of the commodity futures market as crude oil is one of the primary sources of energy, prices of other assets can be affected by the change in crude oil price. Moreover, most energy investments are based on oil price information; and therefore, crude oil futures as a commodity may have an effect on the interplay with equity markets i.e. S&P500 index. Using the VAR-DCC-GARCH model, we estimate time-varying return volatility and the dynamic conditional correlation between return volatilities by capturing seasonality in return and variance. We incorporate seasonality as an exogenous variable in our model, while their model do not control for seasonality. We use two different approaches (i) sub-sample analysis and (ii) commodity-specific measures to assess the impact of financialisation. With sub-sample analysis, we investigate how the results vary between pre-financialisation (1993-2003) and during/post financialisation (2004-

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[5] Interseasonal price volatility provides information on the change in price in the long-run whereas intraseasonal volatility shows the information on the change in price within the growing season (Goodwin and Schnepf 2000).

2019). For commodity-specific measure analysis, we investigate the impact of financialisation as approximated by the change in open interest held by different types of traders and liquidity as aggregated open interest by using regression and Granger causality analysis.[6]

Our key findings can be summarised as follows. To begin with, we note that an increase in the speculation index as measured by the change in net commercial long position dampens the conditional volatility of crude oil futures before financialisation period. On the other hand, the conditional volatility of the crude oil futures decreases with an increase in the open interest (as a measure of liquidity) since financialisation of commodities.

Second, examining the volatility linkage between crude oil futures and equities during the pre-and post-financialisation, we observe the impact of financialisation on time-varying correlation to be inconclusive for both sample periods suggesting financialisation may not directly increase the co-movement between crude oil futures and equities.

Third, by exploring seasonality in variance, our result confirms our hypothesis on seasonality to fade away since financialisation period. This is because the equity market being a larger market can influence the volatility of crude oil futures and crude oil futures started to act more like a financial asset.

Fourth, we investigate the potential impacts of financialisation on the maturity effect and find that the maturity effect to be diminishing since the financialisation of commodity markets. One notable observation for our study represents the rejection of the Samuelson correlation effect in crude oil-equity, which shows that the correlation between crude oil futures and equities increase as the contract further moves away from the underlying contract. We observe this effect to be more prominent since financialisation.

Fifth, we find evidence of speculative activity may drive volatility of equity and crude oil futures to change since financialisation. However, there is no convincing evidence of speculative activity impacting the correlation between crude oil futures and equities. Looking into the causal relationship between liquidity and return volatility, we find that there has been bidirectional causality since financialisation whereas liquidity has no causal link with return volatility before financialisation.

Altogether, we find some evidence that is consistent with effect of financialisation in crude oil futures and equity markets. However, there is no pervasive evidence that financialisation has directly changed volatility patterns and the volatility link between crude oil futures and equity markets. We can not ignore that there could be other drivers altered by the financialisation such as a change in inventory, change in demand level and *etc.*; that might indirectly change the patterns of volatility and volatility link between these markets.

The remainder of this paper is organized into seven sections. After this introductory section, section 2 contains a review of the literature on both theoretical models and empirical findings on cross-market connectedness, volatility and systematic volatility patterns. Section 3 explains the measures and methodology employed for the impact of

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[6] Recently, Ding et al. (2021) use a DCC-GARCH framework to analyse the impact of financialisation on the co-movement between some commodities and equity. Our paper differs from their paper in many ways. For instance, we look into the impact of financialisation on systematic volatility patterns such as seasonality, Samuelson volatility and correlation effect, whereas their paper only focuses on volatility.

financialisation on volatility and correlation followed by section 4 which describes the data employed and preliminary analysis. In section 5 we present the empirical results on various relationships and impacts while we perform a series of robustness checks in section 6. Finally, section 7 concludes by summarizing the key results.

2. Literature Review

This section reviews a number of key issues related to (1) theoretical models dealing with the impact of financialisation on commodity and equity market, (2) empirical findings on cross-market linkage, and (3) systematic volatility patterns of commodity and equity markets.

2.1. Theoretical Models related to Financialisation, Commodity and Equity Markets

There is a relatively small body of theoretical literature on the financialisation of commodities focusing on the trading behaviour of financial investors and its pricing impact.[7] There is continuing debate on the role of non-commercial participants and its' impact on price volatility in the financial market. A brief overview of theoretical models on oil price risk and early influential models that are indirectly linked to financialisation can be found in Appendix A.1.

Most of the theoretical literature on speculation, inventory, commodity price volatility suggest accounting for inventory level is crucial for commodity price dynamics or assessing the impact of speculation on price volatility particularly for storable commodity. This literature is epitomised by studies such as Williams and Wright (1991), Routledge, Seppi, and Spatt (2000) and Vercammen and Doroudian (2014).[8] On the other hand, equity price dynamics do not rely on inventory levels. The differences between commodity and equity markets are driven by the strong ties of commodity derivatives to the underlying physical commodities. Although equity can be transferred and held for any period without cost, storing physical commodity involves significant storage costs. The physical commodity can be stored for future consumption with storage cost but one cannot borrow physical commodity from the future for current consumption. Seasonality in demand or supply creates seasonal variation in prices whereas, storage costs prevents seasonal price variation to be perfectly smoothed out. Consequently, the commodity futures prices are quoted based on delivery dates. Moreover, this price may include an idiosyncratic element, the features of which are specific to the perishability of commodity, delivery location, storage and shipping costs, seasonal effects *etc* (Juvenal and Petrella 2015).

Focusing on financialisation, Basak and Pavlova (2016) construct a dynamic equilibrium model to illustrate the impacts of financialisation on futures prices, volatilities, and correlations among commodities and between commodities and equities. They show that financialisation increases commodity futures prices, their volatilities, and

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[7] See Ekeland, Lautier, and Villeneuve (2019) and Goldstein and Yang (2015) for brief review of theoretical literature.

[8] We deliberately do not go into details of these theoretical models in this paper due to its' focus on agricultural commodity market.

correlation with equity prices by a greater extent for the commodities included in a price commodity index. Moreover, their model indicates how shock from the financial market transmits to future prices as well as commodity spot prices and inventories through stochastic discount factor (marginal rate of substitution of any market participant) channel. In a similar vein, Boons, Roon, and Szymanowska (2012) develop an index of commodity futures prices and suggest that commodity-equity market are connected as investors' need to hedge against commodity risk and their speculation demand in the commodity futures market (once the participation cost is reduced due to financialisation). The study finds a strong pattern in average stock returns that is, stocks with high commodity beta (captures exposure to systematic risk) underperform relative to those with low commodity beta before the financialisation period, while they perform better after the financialisation period.

These theoretical models do not distinct futures contract with different maturities and thus the direct effect of financialisation on the volatility of contracts across different maturities are not explored except for Baker (2021), Isleimeyyeh (2020) and Funk (2017). Our theoretical strategy is based on these studies along with studies mentioned later paragraph. Kogan, Livdan, and Yaron (2009) and Baker (2021) investigate two channels of financialisation of storable commodities particularly for crude oil (i) increase in price by household hedging and (ii) smoothing through inventory and find that volatility (standard deviation) of the crude oil futures price decreases with maturity more steeply in the theoretical model than in the real data. Isleimeyyeh (2020) following Ekeland, Lautier, and Villeneuve (2019) develop a model that examine the link between commodities (both physical and futures market) and stocks. The study indicates that a rise in the correlation between commodity and equity can cause a decrease (increase) in long (short) positions taken by financial investors when the expected stock return is positive. The study show that impact of financialisation depends on financial investors' situation. Moreover, an increase in the net long position taken by financial investors increases the future price as an increase in financial investors participation causes an increase in demand for future positions. Consequently, it leads to a decline in the cost of hedging and hence, inventory holders increase their inventory level and spot price increases. Figure 2 shows how increase in net long position may decrease futures price through the understanding of above mentioned literatures. The inverse effect between cost of hedging and inventory is observed when financial investors take short position. Funk (2017) shows that price feedback from hedging of storage contracts increases futures price volatility and reduces the correlation between the futures prices at different delivery dates.

It is possible to indirectly link speculation and price volatility of contracts across different maturities by using the theoretical model of Samuelson (1965), Anderson and Danthine (1983) and Bessembinder et al. (1996). The Samuelson hypothesis shows a relationship between price volatility and time-to-maturity and states that futures volatility should increase as it nears the delivery date. Anderson and Danthine (1983) provides a new explanation of Samuelson hypothesis and links degrees to uncertainty instead of time-to-maturity. As the information flow is higher near to maturity date, the volatility increases and then Samuelson hypothesis holds. Later, Bessembinder et al. (1996) identify the key condition i.e. the contracts with negative covariance between the spot price and net

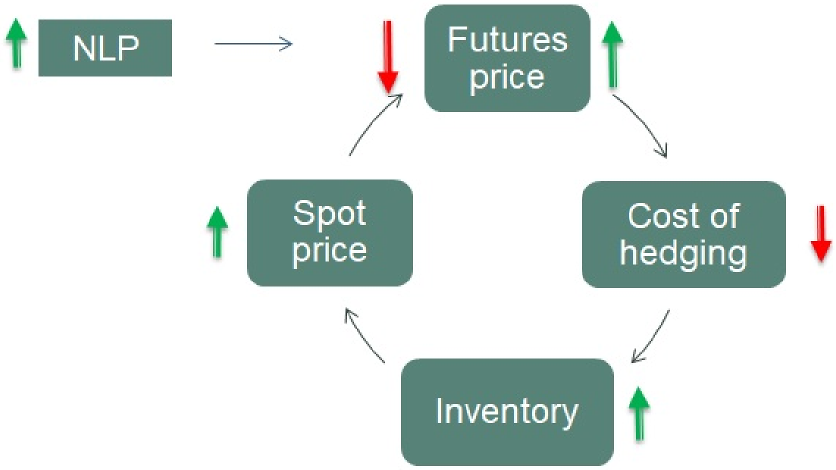

Figure 2: Net long position and futures price relationship

carry cost are most likely to hold Samuelson maturity effect.

Altogether, the theoretical review suggests distinctive views on the relationship between speculative activity and price volatility, and how speculation may impact the volatility of contracts of successive maturities.

2.2. Empirical Findings on Cross-market Link both in Price/Return and in Volatility

While theoretical literature on the impact of financialisation is scarce, the impact of financialisation has received considerable attention in the empirical literature.[9] In this section we review literature on how commodity futures and equity markets can be connected in terms of price, return and volatility and continues with different views on financialisation and change in volatility. Later in the section we provide a brief review on volatility dynamics with an economic explanation of the Samuelson effect, implications of empirical studies on the Samuelson effect and seasonality in crude oil and equity markets.

2.2.1. Cross market integration

The literature on the impact of financialisation on increased integration between financial, energy and agricultural futures markets is epitomized by Silvennoinen and Thorp (2013) and K. Tang and Xiong (2012). In recent literature, Y. Tang et al. (2021) find that price of oil is a predictor of volatility of stock return. Whereas, Christoffersen and Pan (2018) finds that volatility of oil price is a strong predictor for volatility of the overall stock market especially since the financialisation. In a similar vein, Creti, Joëts, and Mignon (2013) explore time-varying correlations between commodities and equity (S&P500 index). They highlight the differences in the correlations between S&P500 and commodities during the 2008 financial crisis and attribute it to the financialisation of commodity markets and demonstrate the deterioration of diversification benefits of commodity futures. Additionally, Silvennoinen

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[9] see Irwin and Sanders (2011); Fattouh, Kilian, and Mahadeva (2013); Cheng et al. (2014); and Natoli (2021) for extensive literature.

and Thorp (2013) show that futures markets positions of non-commercial traders long positions (open interest) affect correlations.

The aforementioned studies provide mixed results on the connection between crude oil and equity markets. Most of the studies supporting the inclusion of commodities in constructing portfolio are based on the observation period before the GFC. Ever since the increase in financial activity in the commodity market, there is an ongoing debate on the link between crude oil and their co-movements with equities. Many of these studies overlook volatility linkage while the change in volatility of one market may affect both spot and futures prices, inventory levels and volatility of other markets. Hence, omitting volatility from studies may lead to varying findings. Moreover, this strand of literature mostly does not account for systematic volatility patterns of commodity prices.

2.2.2. Volatility

In this subsection, we begin with a discussion on the relationship between speculation and volatility, how the volatility of each market may alter and how the volatility linkage of these markets may change due to financialisation. Moreover, this subsection looks into how the volatility of one market may transmit to other markets by a brief explanation of some transmission mechanism.

Most of the studies show mixed views on how financialisation affects the volatility of commodity and equity markets. The competing views concerning the relationship between volatility and speculation are depicted in figure 3. One of the views suggests that increased participation of non-commercial traders reduces the quality of the information in the futures market and may show a destabilizing effect on the price that results in increased volatility. Non-commercial traders in the market may drive prices away from equilibrium values and may result in price bubbles (price boom and busts). Moreover, Weiner (2002) notes that speculators may manipulate the market or if they are not informed properly, they might trade following past trends or observing herding behaviour instead of focusing on market fundamentals.

Conversely, another view suggests that speculators increase market liquidity and will therefore bring efficiency in forecasting future prices, consequently reducing volatility. In particular, Brunetti, Büyükşahin, and Harris (2016) and Filimonov et al. (2014) highlight that financialisation provides liquidity to commodity markets and allows transfer of risk among market participants and facilitate market forces to bring back the prices nearer to its fundamental values.

There are many channels through which crude oil and equity price volatility can be connected such as arrangement of investors' portfolio, commodity index traders (CIT) and rate of information flow. Higher crude oil price could be due to higher cost of production, low level of productivity of labour and capital, low level of disposable income, low level of demand for energy using durable goods or low level of corporate earnings and equity prices. High prices can also mean higher earnings and equity values in the mining, oil, gas and other related industries (Nandha and Faff 2008; El-Sharif et al. 2005). Alternatively, it may not have any impact whatsoever (Chen, Rogoff, and Rossi 2010). For instance, in 2016, there was a sudden fall in oil price which was associated with a 9% drop

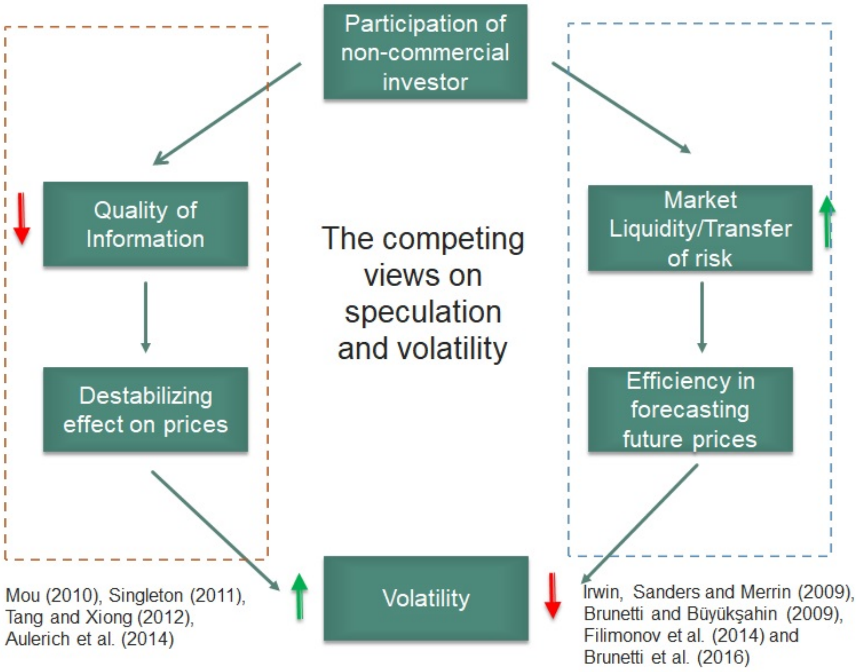

Figure 3: The competing views concerning the relationship between volatility and speculation

in the S&P500 index and this could reflect in link between commodity and equity market volatility (Maghyereh, Awartani, and Bouri 2016). The variation in crude oil price may reflect in change in the expected earnings of oil based industries both in primary and secondary markets. This volatility of oil may create more uncertainty in pricing of equity which are exposed to oil and oil related industries. In particular, Ji and Fan (2012) argue that financialisation fosters transmission of financial asset shocks to commodity markets via different arrangements of investors' portfolios. K. Tang and Xiong (2012) show that CIT creates a channel through which price volatility spills from outside financial markets to commodity markets. They estimate spillover from stock market volatility and dollar (US) volatility to commodity market by accounting for plausible shocks (for example, an oil price shock, turmoil in bond and stock markets) that affect simultaneously non-energy commodity and oil prices.

The volatility of an asset rather than its' return is related to the information flow of a market (Ross 1989). Both trading volume and open interest can be used as a proxy for new information arrival.[10] In this paper, we particularly use open interest as a liquidity proxy.

Sanders and Irwin (2010) find that speculative activity and liquidity are positively related. Floros and Salvador (2016) suspect that open interest and price volatility for some contracts are positively related due to an increase in speculative trading rather than liquidity reasons. This view is later confirmed by Kang, Rouwenhorst, and Tang (2020) showing that speculators instead of demand provides liquidity in the short run. As financialisation increases

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[10] Trading volume is used as a proxy as it is consistent with the sequential information model (Copeland, Economics, and Business 1976) and the mixture of distribution hypothesis (Clark 1973). Open interest includes information on future economic activity (Hong and Yogo 2012) and considered as an alternative measure for dispersion of market participants belief (Shalen 1993; Bessembinder, Chan, and Seguin 1996). Both of these variables shows the overall trading activity of the market.

the number of open interest, the relationship between open interest and price variability may vary depending on market participants' position. Collectively, previous studies provide mixed and inconclusive evidence on price volatility and open interest.

Apart from these studies, some studies distinguish the effect of expected changes and that of unexpected changes in trading volume and open interest on volatility (Girard, Sinha, and Biswas 2007). Similarly, Bessembinder, Chan, and Seguin (1996) suggest that if the change in unexpected open interest is large, it will increase the price variability and both expected and unexpected trading volume increase volatility with the effect greater for the latter than for the former. Recently, studies have proposed that market participants (speculators and hedgers) filter information in a different way and hence, market participants' hedging or trading strategy may differ and can exert a separate impact on price dynamics. In general, non-commercial investors' participation in futures trading increases over time especially the following financialisation. Sanders, Boris, and Manfredo (2004) show that large traders (commercial) decrease their position (long position) when price increases whereas traders (large non-commercial) increase their position. Likewise, Wang (2001) finds that positions taken by both non-commercial and non-reporting do not drive returns but notes weak evidence on commercial position driving returns in selected markets.

2.2.3. Systematic Volatility Patterns

One of the commonly observed features of commodity futures price dynamics is the time-to-maturity or Samuelson hypothesis (recently, maturity effect). Another feature of commodity price dynamics is seasonality in their prices. The Samuelson hypothesis has been extensively tested in a large number of literature including both commodity and financial markets. Though there are some contradictory results in existing literature, there are two common conclusions from these results. Firstly, the seasonal effect is more important than the Samuelson effect, in particular for agricultural commodities (Anderson 1985; Kenyon et al. 1987). Secondly, the Samuelson effect plays an important role in forecasting price volatility across commodities that shows seasonality in demand and supply and such effect applies to financial futures due to the well-defined cost of carry model (Galloway and Kolb 1996). As these factors can explain some variation in commodity price volatility, we investigate more in-depth, how the increase in speculative activity changes the nature of these volatility patterns.

2.2.3.1. Samuelson Hypothesis. There is a large body of empirical literature on the Samuelson hypothesis focusing on different aspects of the Samuelson hypothesis. Some tests whether (1) shocks from physical market influences futures market during the near delivery date, (2) there is decreasing volatility pattern as maturity increases, (3) there is a decreasing correlation between contracts as maturity increases, (4) whether shocks from the physical market may spill to the futures market in a decreasing manner, (5) whether trading volume and open interest affects the Samuelson pattern and (6) influence of news arrival on time to maturity and *etc.* In this subsection, we discuss Samuelson's hypothesis on volatility and correlation and how these effects may change due to increasing speculative activity in the crude oil futures market.

Samuelson hypothesis refers to a phenomenon that volatility of the futures price increases as the contract reaches its' delivery date. This phenomenon is previously suggested by Segall (1956) and Telser (1958). The basis behind the phenomenon relates to shocks to demand and supply and other conditions in the market. According to Samuelson (1965) nearer contracts are exposed to more shock than deferred contracts. This explains the fact that nearer futures contract prices are more sensitive to information arrival due to the fundamentals on converging futures to spot price when the contract approaches expiration and, therefore, increases the volatility of nearer contracts. On the other hand, the deferred contacts are not reflected by a large amount of information.

Prior studies show mixed results for the Samuelson hypothesis. Castelino and Francis (1982) and Miller (1979) findings' support Samuelson's volatility hypothesis. Recently, this effect has been observed for many commodities such as energy and agricultural (among others, Allen and Cruickshank 2002; Bessembinder, Chan, and Seguin 1996; Daal, Farhat, and Wei 2006). The effects are much weaker for metal commodities and non-significant for financial futures (Duong and Kalev 2008; Kan 2001; Moosa and Bollen 2001). Duong and Kalev (2008) and Lautier and Raynaud (2011) suggest that there should be ordering of the volatilities (in the time series) across different maturity of the futures contracts that lead to a decreasing pattern. In recent years, Jaeck and Lautier (2016) identifies that price shocks from the physical commodity market may spill over to the futures commodity market with a reducing magnitude when the maturity of contract increases. The existing empirical evidence is invariably based on the (unconditional) variance as a measure of volatility, although some authors used the interquartile range for the same purpose.

Schneider and Tavin (2018) finds that, for a constant period, the returns of two futures contract become less related as the maturity of the second underlying futures contract increases and moves away from that of the first underlying contract. This has been referred to as *Samuelson correlation effect.* Recently, Hoang Long Phan and Zurbruegg (2020) and Hoàng-Long Phan et al. (2021) examine the Samuelson volatility effect through price-news-sensitivity and information asymmetry. However, they do not include Samuelson correlation effect which is important to examine while looking into volatility link between crude oil and equity markets. To the best of our knowledge, we are second (after Schneider and Tavin (2018)) to investigate the Samuelson correlation effect in equity-commodity market before and during the financialisation period to contribute to the literature.

Samuelson effect is important for futures market participants who particularly rely on price variability information. For instance, information on the Samuelson effect may help speculators to benefit from high price volatility. This is because high volatility near expiry provides liquidity, and therefore, speculators can optimise their position and can earn more return in the short run. Moreover, the maturity effect is also important in margin setting as accordingly to Floros and Vougas (2006), "margin size is a positive function of the volatility of futures prices" i.e. when volatility is increased the margin requirement should set higher. Additionally, in the real world, volatility is not constant (Black and Scholes 1973) as well as not directly observable due to the unobservable rate of information flow. Therefore, it is crucial to account for the maturity effect while looking into the determinants of the volatility of futures prices.

2.2.3.2. Seasonality. In particular, we consider the crude oil futures price as futures markets play an important role in price discovery and hedging against risk. Futures markets help firms to determine the inventory level by the difference between futures prices of subsequent months contracts, however, without the intervention of futures market firms need to rely on their expected price changes for inventory level (Telser 1958, 234). Commodities often show seasonal pattern due to seasonal harvesting season, climate change and *etc.* This allows futures price to indicate the overall supply and demand for spot markets by providing information on intra-season and inter-season price variability. Inter-season price volatility provides information on the change in price in the long-run whereas intra-season volatility shows the information on the change in price within the growing season (Goodwin and Schnepf 2000). For instance, futures price may provide information on the next seasons' production and investment decision and therefore, can minimise inter-seasonal price variability (UNCTAD 2009a, 24). Likewise, determining the optimal level of production or delivery time for physical goods can be reduced by observing intra-seasonal price movement (UNCTAD 2009a, 24). This suggests that seasonality is an important factor in futures price volatility and should be taken into consideration in risk management. If the seasonality is not accounted for, the increased price volatility due to an increase in speculative activity or other events that may be accountable by these trends may increase the overall risk in the markets.

Seasonality is a crucial factor when valuing derivatives in the agriculture and energy market (Back, Prokopczuk, and Rudolf 2013) as commodity future price and volatility shows patterns of seasonality (Maitra 2018; Richter and Sørensen 2005). Seasonal fluctuation in commodity prices can be caused by many factors for example demand for physical commodities that are affected by patterns, cycles and trends in supply, demand and consumption. Particularly, agricultural commodity prices follow a seasonal pattern as production/harvest is at a peak or storage is expensive. Particularly, in most agricultural commodities, price volatility appears to peak during the summer, whereas energy commodities (e.g. heating oil) show seasonality during winter due to high demand. Predictable seasonal fluctuation is reflected in prices. However, these patterns may not be perfectly predictable. Hence, from hedgers and speculators perspective, stochastic seasonality indicates a risk that is reflected in future prices and risk premia (Hevia, Petrella, and Sola 2018). In general, volatility tends to be high in the presence of a demand or supply shock and when inventory is low. In this study, we use the dummy variable to capture the seasonal effect and plan to use the sinusoidal functions approach for our future research.[11]

The stock market shows different seasonal patterns wherein the performance of the market varies across time and these variations follow periodic patterns. Rather than reflecting some underlying economic reality such as supply and demand, the existence of seasonality represents a weak form of market efficiency as it indicates return predictability which should be exploited by arbitrageurs but, perplexing, is not (Fama 1970). Hence, investors should be able to

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[11] A brief review on different model used to capture seasonal effect can be found in Appendix A.1.

build their hedging strategy to earn higher return incommensurate with the degree of risk. Berument and Kiymaz (2001) show seasonality effect (day of the week effect) in both returns and volatility on the S&P500 and suggest that determining volatility pattern of stock market returns by incorporating seasonality allows financial investors to adjust their portfolios. Lucey and Pardo (2005) show various seasonal effects in financial markets such as the value effect, the size effect, the holiday effect, the weekend effect, the momentum effect, the dividend yield effect, and the weather effect, among others. Recently, Alemany, Aragó, and Salvador (2019) assess intraday seasonality on volatility transmission between stock indexes and show that if seasonality is neglected, the model may lose important information on volatility transmission.

Considering the financialisation, it is expected that due to its' substantially larger market size, the equity market influences the commodity market through financialisation than the other way, and hence it should weaken the seasonality of crude oil price volatility. Baur and McDermott (2010) empirically show that commodity loses its traditional real characteristics and acts more like financial assets and thus volatility is not influenced by the seasonality of the underlying demand and supply. These are the basis of our hypothesis on financialisation weakening seasonality of crude oil volatility.

3. Methodology

In this section, we describe the theoretical background behind the specific approach we consider to capture volatility and linkage between crude oil and equity markets for further analysis. To assess the impact of financialisation, we use two approaches (i) sub-sample analysis and (i) commodity-specific financialisation measure. At first, we explore various frameworks used in empirical literature on estimating volatility and correlation between commodity and equity markets can be found in Appendix A.1; including what models we consider and why we consider such models. Then, we present our method on (1) how to model time series (log returns to commodity futures prices and equities) using our chosen econometric model, (2) how we examine volatility and co-movements simultaneously in the model, and (3) how we extend these models to account for seasonality commodity prices. We conclude the section by discussing the approach taken for commodity-specific measure to analyse the link between various variables to investigate the impact of financialisation.

3.1. Capturing Volatility and Cross-market Connectedness

We consider the VAR-GARCH model with DCC specification as this model can simultaneously estimate the mean and volatility cross-effects between the commodity futures and equity markets. The idea behind using VAR framework is to measure lead-lag relationship between return volatility. Moreover, volatility are influenced to varying degree by (i) past volatility in another market, (ii) it's own past volatility. Whereas DCC-GARCH model can provide us information on the origins and directions of the shocks along with intensity of the volatility transmission between these markets while allowing correlation to be time varying. Some recent papers have adopted the VAR-GARCH approach to investigate volatility spillover and trading strategies between oil/commodity and equity markets (among others, Büyükkara, Enginar, and Temiz 2020; Maghyereh, Awartani, and Tziogkidis 2017).

The VAR process is performed in three steps: determination of lag length, estimation of model, and diagnostics of model. To keep the model simple we chose VAR(1) process. Our presentation slightly deviates from standard VAR mean equation as we investigate to what extent exogenous seasonality impacts on return/variance of the assets. Before seasonal dummies are included as exogenous variable in the model, a joint significance test of all seasonal dummies is tested by likelihood ratio (LR) test.[12] The regression model follows a vector autoregressive (VAR) progress with exogenous variable (X), where the conditional mean equation is specified as below

$$r_t = \mu_t + \Phi r_{t-1} + \Psi d_t + \varepsilon_t; \quad \varepsilon_t | F_{t-1} \sim N(0, H_t) \tag{1}$$

where, F_{t-1} stands for all information available up to $t-1$, $r_t = (r_t^{S\&P500}, r_t^{CL01}, r_t^{CL02}, r_t^{CL03}, r_t^{CL04})'$ is a $k \times 1$ dimensional vector representing returns at time t on $k = 5$ assets, and in particular the S&P500 equity index ($r_t^{S\&P500}$), crude oil nearby futures contract (1st nearest contract) (r_t^{CL01}), crude oil next futures contract (2nd nearest contract) (r_t^{CL02}), crude oil distant futures contract (3rd nearest contract) (r_t^{CL03}) and crude oil most distant futures contract (4th nearest contract) (r_t^{CL04}), $\mu_t = (\mu_t^{S\&P500}, \mu_t^{CL01}, \mu_t^{CL02}, \mu_t^{CL03}, \mu_t^{CL04})'$ is a $k \times 1$ vector of constant terms, Φ is time-invariant $k \times k$ matrices of coefficients with elements $[\Phi]_{ij} = \phi_{ij}$, where $i, j = (S\&P500, CL01, CL02, CL03, CL04)$; Ψ is $k \times 3$ vector of coefficients of seasonal dummy; $d_t = (d_t^{winter}, d_t^{summer}, d_t^{fall})'$ is a 3×1 vector where $d_t = 1$ if the season is winter, summer, fall and is 0 otherwise; and $\varepsilon_t = (\varepsilon_t^{S\&P500}, \varepsilon_t^{CL01}, \varepsilon_t^{CL02}, \varepsilon_t^{CL03}, \varepsilon_t^{CL04})$ is a $k \times 1$ vector of the residual returns in r_t.

From Equation (1), we test for return spillover by testing $\phi_{ij} = 0, \forall i \neq j$. We use three dummies that represent seasonal effect and select winter as a reference. Hence, seasonality can be detected by comparing the coefficients of seasonal dummy variables estimated by the mean equation. For example, if ψ in the mean equation is positive and significant, it means returns during winter are effected by seasonality.

The VAR process is estimated by maximum likelihood method. In total, we estimate six DCC (1,1) models allowing for or disregarding the presence of the VARX component in the mean equation with three different error distribution (Normal, t-Student and Laplace). Brief results are presented in Table C.3.1 in Appendix C.3. We choose the best fitting model with the minimal information criteria. In the Section 5.1.1, in Table 2, we present the result of multivariate VAR modelling estimates including standard errors with significance level for pre-financialisation and post-financialisation period.

The final step of VAR process is diagnostic tests for which summary of statistical properties of the VARX model are presented in 3. One of the issues with high frequency financial data is the presence of strong serial correlation and volatility clustering. Arch-LM test in error term in Equation (1) and Ljung-Box tests to the raw

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[12] see Section A.1.4 in Appendix A.1 for LR test.

and squared residuals of Equation (1) are performed; which shows that the residuals of VARX component contain high autocorrelation and heteroscedasticity. Moreover, Weighted-box test is perform to detect any ARCH effect. The Jarque-Berra test results show that error term is leptokurtic distributed. As there are still some unexplained volatility left in the model, that shortcoming is addressed by fitted DCC GARCH model and later by OLS regression analysis.

In order to estimate conditional volatility, we use of the residuals derived in equation (1). The DCC GARCH parameters are determined by using estimated univariate GARCH models. Optimal univariate GARCH model has been chosen from variety of GARCH specification as explained by Teräsvirta (2009). Poon and Granger (2005) suggest that GARCH(1,1) specification yields in most cases the best results. In addition to that, the Lagrange multiplier test for all the assets indicates the presence of ARCH effects in the residuals of the OLS estimate of the model. Thus, we select a GARCH (1,1) specification. Our result is similar to previous studies to select one lag for variance equation. The standard multivariate GARCH framework is applied, where S&P500 and crude oil futures returns are assumed to be conditionally multivariate normal with zero expected value and a symmetric $k \times k$ time-varying covariance matrix, H_t

$$\varepsilon_t = H_t^{\frac{1}{2}} \upsilon_t, \upsilon_t \sim N(0,1) \tag{2}$$

where $\upsilon_t = (\upsilon_t^{S\&P500}, \upsilon_t^{CL01}, \upsilon_t^{CL02}, \upsilon_t^{CL03}, \upsilon_t^{CL04})'$ is a $k \times 1$ vector of independently and identically distributed errors. H_t is a symmetric $k \times k$ conditional variance-covariance matrix that includes the time-varying conditional volatilities on the main diagonal as $[H_t]_{i=j} = h_{ii,t}$, and the time-varying conditional covariances on the off-diagonal elements as $[H_t]_{i \neq j} = h_{ij,t}$. Moreover, following Engle (2002) H_t takes on the following form

$$H_t = D_t R_t D_t \tag{3}$$

where $D_t = diag(\sqrt{h_t^{S\&P500}}, \sqrt{h_t^{CL01}}, \sqrt{h_t^{CL02}}, \sqrt{h_t^{CL03}}, \sqrt{h_t^{CL04}})$ represents a $k \times k$ diagonal matrix of dynamic standard deviations in the residual returns of $r_t^{S\&P500}, r_t^{CL01}, r_t^{CL02}, r_t^{CL03}$ and r_t^{CL04} respectively; and R_t is a symmetric $k \times k$ matrix of time-varying conditional correlation coefficients that includes $[R_t]_{ij} = \rho_{ij,t}$. The standard disturbance of R_t is ϵ_t i.e. $\epsilon_t = D_t^{-1} \varepsilon_t$ The conditional variances are derived through a first order univariate GARCH (1,1) process, as follows

$$h_t = \omega + A\varepsilon_{t-1}^2 + Bh_{t-1} + \gamma d_t \tag{4}$$

where $\omega = (\omega^{S\&P500}, \omega^{CL01}, \omega^{CL02}, \omega^{CL03}, \omega^{CL04})$ is a column vector of constant terms; $[A]_{ij} = \alpha_{ij}$ and $[B]_{ij} = \beta_{ij}$ are $k \times k$ matrices, where $i, j = (S\&P500, CL01, CL02, CL03, CL04)$. The transmission effect is observed through α_{ij} that represents effects of past return shock i.e. short term persistence and β_{ij} shows volatility clustering or long term persistence/dependency on current conditional variance. In the general GARCH model, conditional variance h_t depends on the squared residuals ε_{t-1}^2 and lagged value h_{t-1}. In our model, we extend the model to include three seasonal dummies to capture seasonal effect in conditional volatility and conditional correlation. Similar to mean equation, seasonal dummy coefficient γ in variance equation represents whether seasonality affects volatility or not.

In order to estimate pairwise conditional correlation coefficients between equity index returns and crude oil futures returns i and j at period t can be expressed as follows. The QMLE estimation method is described in Appendix A.1.

$$\begin{aligned} \rho_{ijt} &= \frac{E_{t-1}[\varepsilon_{it}\varepsilon_{jt}]}{\sqrt{E_{t-1}[\varepsilon_{it}^2]}\sqrt{E_{t-1}[\varepsilon_{jt}^2]}} = \frac{E_{t-1}[\sqrt{h_{it}}\upsilon_{1t}\sqrt{h_{jt}}\upsilon_{jt}]}{\sqrt{E_{t-1}[h_{it}\upsilon_{it}^2]}\sqrt{E_{t-1}[h_{jt}\upsilon_{it}^2]}} \\ &= \frac{E_{t-1}[\upsilon_{it}\upsilon_{it}]}{\sqrt{E_{t-1}[\upsilon_{it}^2]}\sqrt{E_{t-1}[\upsilon_{jt}^2]}} = E_{t-1}[\upsilon_{it}\upsilon_{jt}] \end{aligned} \tag{5}$$

where

$$E_{t-1}[\upsilon_{it}^2] = E_{t-1}[h_{it}^{-1}\varepsilon_{it}^2] = h_{it}^{-1}E_{t-1}[\varepsilon_{it}^2] = 1 \tag{6}$$

The correlation coefficients in ρ_{ijt} form the time varying correlation matrix R_t, where its' diagonal elements are equal to 1. The unconditional variance estimate used in the model (denoted by Q_t) can be expressed by the following

$$Q_t = E_{t-1}[\upsilon_t{\upsilon_t}'] \tag{7}$$

then R_t can be rewritten as

$$R_t = [diag(Q_t)]^{-\frac{1}{2}}Q_t[diag(Q_t)]^{-\frac{1}{2}} \tag{8}$$

where Q_t is a $k \times K$ symmetric positive-definitive matrix. Thereafter, the correlation coefficient $\rho_{ij,t}$ should be parametrised. To achieve that the model assumes that Q_t follows an autoregressive process. This would entail that

$$Q_t = \overline{Q}(1-\theta_1-\theta_2) + \theta_1\epsilon_{t-1}\epsilon_{t-1}^{'} + \theta_2 Q_{t-1} \tag{9}$$

where θ_1 and θ_2 are scalar parameters that capture the effects of past shocks and DCCs on current DCCs. θ_1 and θ_2 are non-negative i.e.$\theta_1 \geq 0$ and $\theta_2 \geq 0$ and $\theta_1 + \theta_2 < 1$, which ensures that Q_t is positive and mean-reverting, while the elements of $[Q_t]_{ij} = q_{ij,t}$ is dynamics conditional covariances between assets i and j. This property implies that in the event of a shock, the correlation between the underlying assets will return to it's long run unconditional level. $\overline{Q}$ is an unconditional covariance matrix of standard residuals ϵ_t i.e. $\overline{Q} = \mathrm{Cov}[\epsilon_t \epsilon_t^T] = E[\epsilon_t \epsilon_t^T]$ and can be estimated as

$$\overline{Q} = \frac{1}{T} \sum_{t=1}^{T} \epsilon_t \epsilon_t^T$$

The unconditional correlations are used as predetermined values in this step (Engle 2002).

In the next stage of diagnostic procedure, we test for the standardized residuals for the presence of variance clustering and normality of error term distribution.[13] We perform test to check whether the residuals behave like a white noise process with the Ljung-Box test. We find no statistically significant evidence of autocorrelation in the standardized residuals or squared standardized residuals at the 1% level in most of the cases. Finally, the Lagrange multiplier (LM) test is performed in order to investigate whether the standardized residuals exhibit ARCH behaviour (Bauwens, Laurent, and Rombouts 2006; Minović 2008). Most of the series presents of no ARCH effects with rare exceptions. Moreover, we apply weighted Ljung and Box (1978) test on standardized squared residuals as weighted portmanteau test is powerful for time series (Fisher and Gallagher 2012; Gallagher and Fisher 2015). The remaining ARCH effect and autocorrelation are negligible and can be explained further with regression analysis part.

3.2. Analysing Impact of Financialisation

This section presents the methodology used to assess the impact of financialisation on commodity futures and equity markets. We show how own volatility of these assets and their volatility link changes due to speculative activity. We discuss the methods (both parametric and non-parametric) used to analyse maturity and correlation effects in section 5.1.6.

Once the DCC-GARCH model, defined in Equation (1) - Equation (9) is estimated, the model's estimated conditional volatility and conditional correlation is used to investigate the impact of financialisation. Before exploring the relationship among three measures of speculation (including robustness check measures), two measures of liquidity factors (including detrended series), five conditional volatility series and four conditional correlation series, we make sure the data is first difference stationary except for data used for non-parametric method where we use raw data extracted from the model.

We perform standard diagnostic tests for conditional volatility and conditional correlation both in level and first difference series. All series are examined with mean, minimum and maximum for any outliers, ADF test and KPSS test for stationarity.[14] The results indicate that before (after) financialisation period conditional volatility (conditional correlation) series are not stationary at level and their first difference become stationary.

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[13] These results are available on request.

[14] The test results are available on request.

3.2.1. Linkage between Conditional Correlation and Condtional Volatility

We use regression analysis to investigate relationship between conditional correlation and conditional volatility as follow

$$\rho_{ij,t} = \xi_0 + \xi_1 h_{i,t} + \sum_{t=1}^{4} \xi_2 h_{j,t} + \vartheta_{ij,t} \tag{10}$$

where ξ_0 is a constant and $\vartheta_{ij,t}$ is standardised error term, $h_{i,t}$ is conditional volatility of S&P500 Index, $h_{j,t}$ is crude oil futures conditional volatility and j is various maturity contract in 4×1 vector form. Equation (10) allows us to address hypotheses on the impacts of price volatility on their correlation by the significance of the coefficient ξ.

3.2.2. Linkage among Conditional Volatility of the Assets

We use regression analysis to assess relationship between conditional volatility of crude oil futures and equity markets. In the first regression, we keep conditional volatility of crude oil futures dependent on the conditional volatility of equities as follows

$$h_{j,t} = \Xi_0 + \Xi_1 h_{S\&P500} + \vartheta_{i,t} \tag{11}$$

where Ξ_0 is a constant and $\vartheta_{j,t}$ is standardised error term, $h_{j,t}$ is crude oil futures' conditional volatility where j is various maturity contract in 4×1 vector form, and $h_{S\&P500}$ is conditional volatility of S&P500 Index and an explanatory variable. Equation (11) allows us to analyse the impact of the conditional volatility of equities on the conditional volatility of crude oil futures by the significance of the coefficient Ξ.

In the second regression, we keep conditional volatility of equities to be dependant on conditional volatility of crude oil futures as follows

$$h_{S\&P500} = \Upsilon_0 + \sum_{t=1}^{4} \Upsilon_1 h_{j,t} + \vartheta_{j,t} \tag{12}$$

where Υ_0 is a constant and $\vartheta_{j,t}$ is standardised error term, $h_{S\&P500}$ is conditional volatility of S&P500 Index, $h_{j,t}$ is crude oil futures' conditional volatility and j is various maturity contract in 4×1 vector form. Equation (12) allows us to analyse the impact of the conditional volatility of crude oil futures on the conditional volatility of equities by the significance of the coefficient Υ.

These regression would show how the volatility of equity impacts volatility of commodity and vice versa and how these relationship changes due to financialisation.

3.2.3. Testing Impact of Financialisation on Conditional Volatility of the assets

Estimated conditional volatility $h_{ij,t}$ is used to examine the relationship with speculation index (SI_i) and open interest (OI_i). The following OLS regression is used to analyse the effect of financialisation of commodity on the conditional volatility of equity and commodity return series.

$$h_{ij,t} = \zeta_0 + \zeta_1 SI_i + \zeta_2 OI_i + e_{ij,t} \tag{13}$$

where ζ_0 is a constant and $e_{ij,t}$ is residual error term. Equation (13) allows us to address hypotheses on the financialisation's impacts on price volatility by the significance of the coefficient ζ_1 and open interest's impact on price volatility by ζ_2. In particular, the hypotheses state that financialisation increases volatility of nearby contracts by greater extent than more distant contracts. The differential impacts will be examined on the estimated volatility. In order to examine the role of increased trading activity of crude oil futures markets in the volatility behaviour, we also use as in a large part of related studies- the common and suitable methodological framework of the Granger-causality (Granger 1969).

3.2.4. Testing Impact of Financialisation on Market Dependency

To evaluate the impact of the financialisation of commodities on the link between crude oil futures and equities, we use the estimated of dynamic conditional correlations of pairwise equity index and crude oil futures with different maturities and follow the below regression:

$$\rho_{ij,t} = \eta_0 + \eta_1 SI_i + \eta_2 OI_i + v_{ij,t} \tag{14}$$

where η_0 is a constant and $v_{ij,t}$ is residual error term. The significance of the coefficient η_1 and η_2 allow us to assess whether there is any impact of financialisation and open interests on the dynamic correlation.

3.3. Granger-Causality Tests

The Granger (1969) approach to the information of whether or not x causes y is to analyse how much of the current y can be interpreted by past values of y, and then to see whether or not adding lagged values of x can improve the explanation. It is said that y is Granger-caused by x if x explains in the prediction of y, or equivalently if the coefficients on the lagged x's are statistically significant. There is also possibility of having two-way causation; where x Granger causes y and y Granger causes x.

3.3.1. Conditional Volatility and Speculative Activity

To assess whether or not speculative activity prompts, in a forecasting sense, price volatility and/or vice versa, the Granger causality test is carried out. We test Granger causality tests to assess the relationships between speculative activity ($SI_{i,t}$) and volatility ($h_{ij,t}$); i.e. if speculative activity 'causes' price volatility (speculation → volatility), if it is volatility that Granger-causes speculative activity (volatility → speculation), if there is a bilateral causality (speculation ↔ volatility), or if there is no significant relationship between crude oil futures and equity index. The test is based as following

$$SI_{i,t} = \tau_0 + \sum \varpi_k SI_{i,t-k} + \sum \varphi_k h_{ij,t-k} + \epsilon_t \tag{15}$$

$$h_{ij,t} = \varrho_0 + \sum \aleph_k h_{ij,t-k} + \sum \varsigma_k SI_{i,t-k} + \varepsilon_t \tag{16}$$

under the following null hypothesis that implies conditional volatility does not Granger-cause speculative activity and alternative hypothesis that implies conditional volatility Granger-causes speculative activity

$$H_0 : \varphi_1 = \varphi_2 = ...\varphi_k = 0 \;\text{ vs. }\; H_1 : \varphi_1 \neq \varphi_2 \neq .....\varphi_k \neq 0 \tag{17}$$

Similarly, null hypothesis that speculative activity does not Granger-cause conditional volatility against alternative hypothesis that implies speculative activity Granger-causes conditional volatility against alternative hypothesis

$$H_0 : \varsigma_1 = \varsigma_2 = ...\varsigma_k = 0 \;\text{ vs. }\; H_1 : \varsigma_1 \neq \varsigma_2 \neq .....\varsigma_k \neq 0(\#eq : twenty_one) \tag{18}$$

To perform similar causality test with regards to open interest and volatility, we replace speculation index with open interest.

3.3.2. Conditional Correlation and Speculative Activity

We also test Granger causality tests for the relationships between speculative activity ($SI_{i,t}$) and dynamic conditional correlation ($\rho_{ij,t}$); i.e. if speculative activity 'causes' conditional correlation (speculation → correlation), if it is volatility that Granger-causes speculative activity (correlation → speculation), if there is a bilateral causality (correlation ↔ volatility), or if there is no significant relationship between the two variables for crude oil futures and equity index. The test follows the vector autoregressive model defined as below

$$SI_{i,t} = \tau_0 + \sum \varpi_k SI_{i,t-k} + \sum \varphi_k \rho_{ij,t-k} + \epsilon_t(\#eq : twenty_two) \tag{19}$$

$$\rho_{ij,t} = \varrho_0 + \sum \aleph_k \rho_{ij,t-k} + \sum \varsigma_k SI_{i,t-k} + \varepsilon_t(\#eq : twenty_three) \tag{20}$$

under the following null hypothesis that implies conditional volatility does not Granger-cause speculative activity and alternative hypothesis that implies conditional volatility Granger-causes speculative activity

$$H_0 : \varphi_1 = \varphi_2 = ...\varphi_k = 0 \;\text{ vs. }\; H_1 : \varphi_1 \neq \varphi_2 \neq .....\varphi_k \neq 0(\#eq : twenty_four) \tag{21}$$

Similarly, null hypothesis that speculative activity does not Granger-cause conditional volatility against alternative hypothesis that implies speculative activity Granger-causes conditional volatility against alternative hypothesis

$$H_0 : \varsigma_1 = \varsigma_2 = ...\varsigma_k = 0 \quad \text{vs.} \quad H_1 : \varsigma_1 \neq \varsigma_2 \neq .....\varsigma_k \neq 0 (\#eq : twenty_five) \tag{22}$$

To explore causal effect between open interest and correlation, we use open interest variable instead of speculation index variable and perform the test.

4. Description of Data

In this chapter, we first describe in Section 4.1, the dependent and explanatory variables that we use for the analysis, including sources of data and graphical analysis of data in Section 4.2. We explain the necessary adjustment of the data series for the purpose of our analysis; for example, how time series (log return series) is generated for further investigation. We provide preliminary descriptive statistics for the derived characteristics such as mean, median, standard deviation and *etc* in Section desc. The section concludes with a overview of preliminary analysis.

4.1. Dependent and Explanatory Variables

For our analysis, we consider crude oil futures from commodity market for several reasons. Firstly, it is the most traded contract at NYMEX in the energy sector. Moreover, WTI crude oil contracts has the highest weight (25.31%- based on reference percentage Dollar weights (RPDW)- May 07, 2020 data) (S&P Dow Jones Indices 2020).[15] As crude oil is one of the primary sources of energy, prices of other assets can be affected by the change in crude oil price. Moreover, most energy investments are based on oil price information; and crude oil futures as a commodity may have an effect on the interplay with equity markets. Therefore, it is interesting to investigate their price and volatility dynamics.

We use S&P500 as the benchmark for equity market as S&P500 is created based on stocks on size, profitability, trading liquidity, diverse mix of industries to reflect broader economy. Moreover, S&P500 tracks most successful companies which tends to provide best investment returns. S&P500 Index is vastly used as proxy for equity market in the academia such as Balcilar, Ozdemir, and Ozdemir (2019), Mensi et al. (2013); Bianchi, Drew, and Fan (2015) and *etc*.

Gorton and Rouwenhorst (2006) views 'non-commercial' traders as financial investors due to that fact that under this category primarily money managers, hedge funds or speculators invests in the futures market. Moreover, these hedge fund managers invest in smaller funds by taking long or short positions in the futures markets (Haigh, Hranaiova, and Overdahl 2005). Thus, we consider financial investors taking short and long position for speculative activities. We choose weekly frequency of time series on the basis of availability of speculators positions data in the US Commodity Futures Trading Commission (CFTC) Aggregated Commitment of Traders (CoT henceforth) Report. CoT Report data are collected every Tuesday and made available to the public on the next Friday at

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[15] based on average contract reference prices for the 2020 annual calculation period.

3:30pm EST. The data on total open interest positions are divided into two categories (till 2009)- 'commercial' and 'non-commercial' and four categories (from 2009) - 'traditional commercial (producers, processors, commodity wholesalers or merchants, and *etc.*),' 'commodity swap dealers' (CITs), 'managed money traders' and 'other non-commercial positions.' Even though crude oil futures are available from 1986, CFTC weekly data is only available from January 1993, before that data was available in fortnightly basis. Moreover, using monthly data may mask the volatility transmission channel and time aggregation (Singhal and Ghosh 2016; El Hedi Arouri, Jouini, and Nguyen 2011). Weekly data may resolve these issues by reducing any potential biases arising from data being not synchronous between crude oil futures, equity market and CFTC data.

Finally, we use crude oil aggregate open interest data to analyse how liquidity factor may impact on the volatility and linkage between crude oil futures and equities.

4.1.1. Futures Return

We extract daily settlement price of NYMEX WTI crude oil futures contracts and S&P500 index from the U.S. Energy Information Administration (EIA) and Yahoo Finance [https://uk.finance.yahoo.com] respectively. The study span ranges from January 05, 1993 to December 24, 2019. The selected time frame allow us to evaluate the impact of financialisation on commodity and equity markets including pre and post financialisation period. The considered crude oil futures contracts are monthly contracts with different maturity. Each crude oil futures contract involves 1,000 barrels of oil. Crude oil futures price of contract 1 in January 1993 (continuous series) represents the earliest delivery date (February 1993 WTI) whereas contract 2, 3, and 4 represent the 2^{nd},3^{rd}, and 4^{th} successive delivery month respectively following contract 1. We take 2^{nd}, 3^{rd}, and 4^{th} consecutive month's contracts as the maturity period is longer compared to front month contract. We forward fill to fill up missing data due to non trading days (26 days) for NYMEX crude oil futures in comparison with S&P500 index data, totalling of 6795 observation. We create the weekly log return series by taking weekly frequency ending every Tuesday of each week as Adhikari and Putnam (2019). Asness, Moskowitz, and Pedersen (2013) and Moskowitz, Ooi, and Pedersen (2012) also create a monthly return series with the same process. As logarithmic data possess good statistical characteristics, we calculate the return series as continuously compounded return by taking first-order natural logarithm differences of two successive weekly prices at week t and $t-1$ as: $r_{i,t} = \ln(P_{i,t}) - \ln(P_{i_{t-1}}); i = 1, 2, ..., 5$; where $r_{i,t}$ is price return of *i-th* market.After converting to weekly series, we have a total of 1407 observation for which 573 observation for pre-financialisation period and 834 for post-financialisation period.

4.1.2. Measure of Financialisation through the Extent of Speculative Activity

In order to measure financialisation, previous empirical studies have used several indicators. Working's (1960) "T" index constructed as a ratio of non-commercial participants' activities to the commercial participants' activities, is one of the most popular proxy for speculation. This measure, however, tends to overstate the speculative activities when applied to the CFTC data due to the presence of "non-reporting" category.[16] Other commonly used speculation indicators include trading volume and open interest in futures contract (Domanski and Heath 2007), ratio of trading volume to open interest in futures contracts, share of open interest held by non-commercials (Büyükşahin and Robe 2014), difference between long and short positions held by non-commercials (Brunetti, Büyükşahin, and Harris 2016). Some of these papers mentioned above include trading volume to measure speculation index as trading volume represents liquidity. Speculative pressure defined as difference between non-commercial long and non-commercial short positions by total non-commercial position is used as proxy for speculation as Sanders, Irwin, and Merrin (2010). For this study, we follow the below speculation measure as our main proxy for financialisation following Hedegaard (2011),

$$\text{Speculation Index} = \frac{\text{Non-commercial Long Position} - \text{Non-commercial Short Position}}{\text{Total Open Interest}} \tag{23}$$

The reasons we use this proxy are as below (1) it is a relative measure and easily comparable with other speculative index (See De Roon, Nijman, and Veld 2000) , (2) it includes net non-commercial position which is affected by financialisation, (3) this index is highly correlated with "speculative pressure" as defined by Brunnermeier, Nagel, and Pedersen (2008) and Sanders, Irwin, and Merrin (2010), and (4) it indicates the long term effect of speculative activity.

Equation (23) measures whether speculators are net long or short in aggregate, and scales their net position by the total open interest. In empirical literatures, for example, Büyükşahin and Robe (2014) and Manera, Nicolini, and Vignati (2016), often uses 'non-commercial' traders as speculators and 'commercial' traders as hedgers. 'Non-commercial' traders are not the only ones that are taking speculative position in CoT report. 'Non-reporting' category also includes long-short speculative position. However, we exclude 'non-reporting' speculators as their position size is below reporting level. Moreover, Bohl, Branger, and Trede (2019) shows that including or excluding non-reported traders as a measure of speculative activity do not change the influence of speculative activity. As our study focuses on financialisation, we focus on speculators rather than hedgers. A negative of net speculator position resembles hedgers position i.e. speculators and hedgers take opposite position side.

We particularly use 2004 as a beginning point for financialisation period as several related empirical literature dates the start of the financialisation of commodity futures around 2004 (Büyükşahin, Haigh, and Robe 2010; Sanders, Irwin, and Merrin 2010; K. Tang and Xiong 2012 among others), and some of these studies explicitly test for and confirm a structural break around 2004.[17]

We also consider two other speculative measure to check robustness in Section 6. As a first measure of robustness

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[16] CFTC defines non-reportable category as follows: "The long and short open interest shown as Non Reportable Positions is derived by subtracting total long and short Reportable Positions from the total open interest. Accordingly, for Non Reportable Positions the number of traders involved and the commercial/non-commercial classification of each trader are unknown." (see https://www.cftc.gov/MarketReports/CommitmentsofTraders/ExplanatoryNotes/index.htm)

[17] We deliberately do not create sample of de-financialisation (for example, Adams, Collot, and Kartsakli (2020) uses July 2014 to January 2019 period data under de-financialisation sample) as sample size is smaller to run a DCC-GARCH model.

check, we use ratio of the market share of long position of speculators over total long positions. Secondly, we use speculative pressure as defined above.

4.1.3. Liquidity Factor

The total number of contracts on crude oil futures that are still open or not yet exercised by market participants are known as open interest of crude oil. It is reported at the end of each trading day. Hong and Yogo (2012) find that aggregate open interest in the commodity futures market is a powerful pro-cyclical predictor of commodity returns and provide better signal for macroeconomic effect that represents real economic activity. Open interest also shows the evolution of investment in futures contract change in the market. Hence, one of the motivations to include open interest as an additional predictor variable is its' explanatory power. Moreover, futures aggregated open interest is often used as a proxy for financialisation of commodity markets (Algieri and Leccadito 2017; Fratzscher, Schneider, and Van Robays 2014; Hong and Yogo 2012). Additionally, as open interest is a standard measure for liquidity factor (Bessembinder and Seguin 1993; Martinez and Tse 2008; Ripple and Moosa 2009), we use open interest as one of the explanatory variables for the regression model. We use aggregated open interest data from weekly CFTC CoT reports and convert the data in millions for better comparison. For robustness of the result in Section 6, we also use detrended open interest series using dummy for each season.

4.2. Graphical Analysis of Data

Turning to graphical analysis of dataset, Figure 4 presents the evolution of the crude oil futures and equity index in price levels over full the sample period for daily price series (left) and weekly log return series (right). It is evident from Figure 4 the crude oil futures price tend to increase since end of 2000. There is a change in oil price and volatility during 2002 bubble. During this period S&P500 index price drop and increase volatility is noticed. The crude oil futures price has a notable spike in 2008 (the price of crude oil reached 147 dollar per barrel, 1 July 2008), followed by a dramatic decrease towards the end of 2008 (the price of crude oil dropped to 39 dollar per barrel) and beginning of 2009 and again a big drop starting in the second half of 2014. Large swings in the level of equity indices are also appeared in Figure 4 associated with the 2008 Global Financial Crisis which started with the collapse of Lehman brothers in August. Moreover, both crude oil futures and S&P500 index have price drop in the beginning of 2011 and 2018.

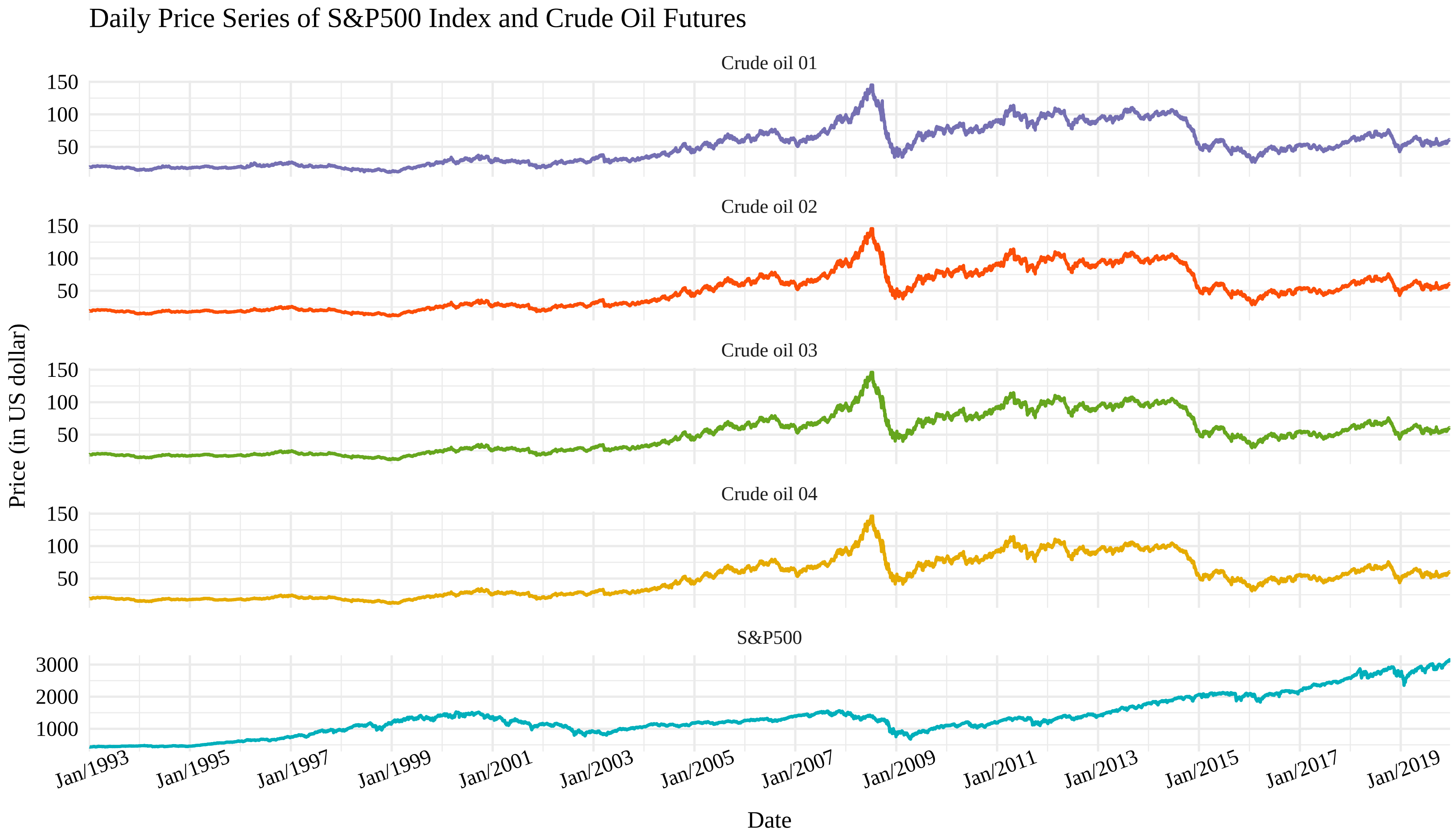

Figure 4: Daily price series of S&P500 and crude oil futures and weekly log-return series of S&P500 and Crude oil futures

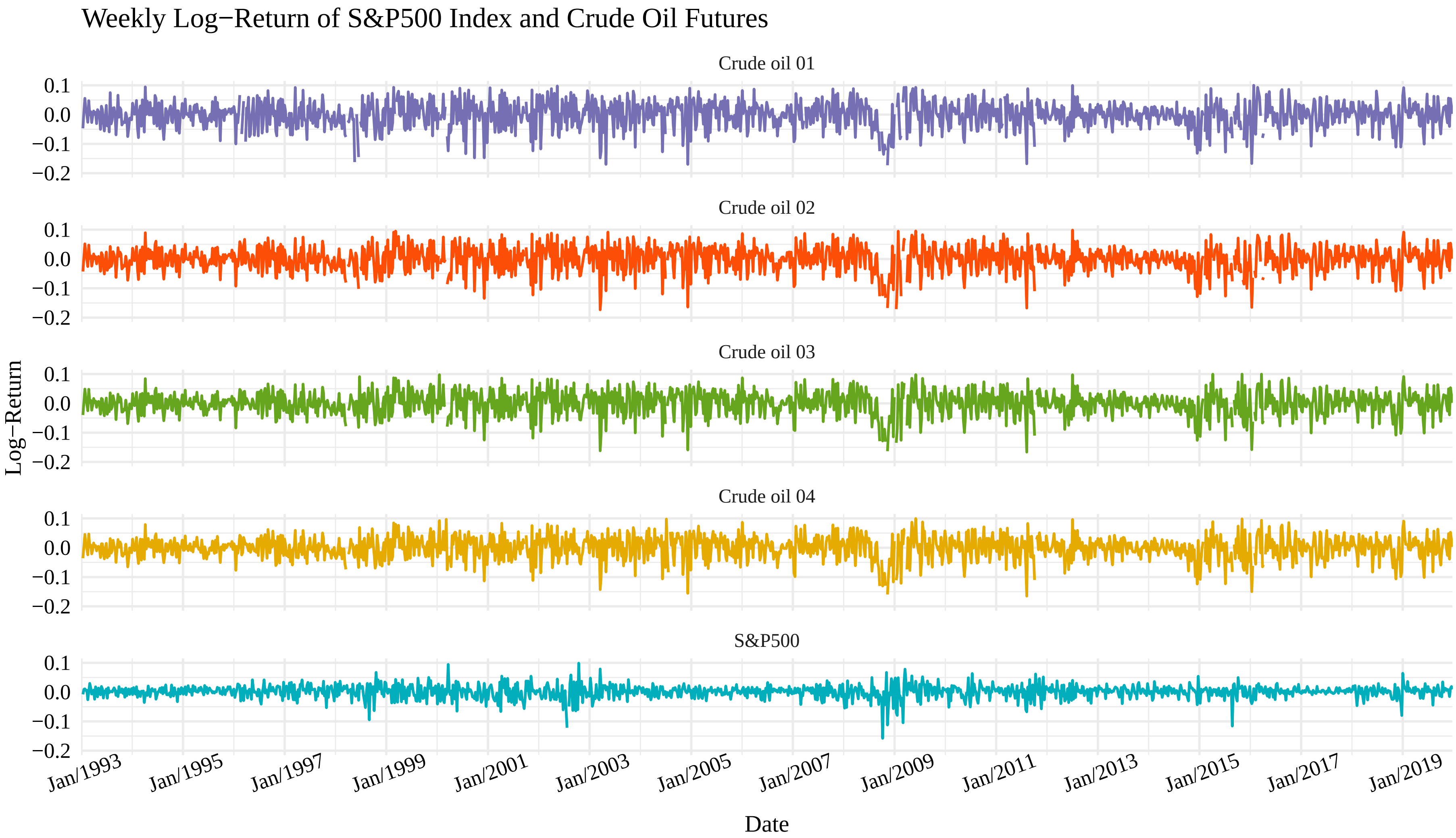

Figure 5: Weekly log-return series of S&P500 and Crude oil futures

When crude oil futures share some common peaks and troughs in their volatilities, it is noticeable in the Figure 5 that since 2000, crude oil futures market volatility started to increase and in particular in 2004. However, the most striking peak was noticed during the financial crisis period. S&P500 index shows similar volatile nature during the crisis period. During both pre- and post-financialisation period, the return series shows the stylized facts of volatility clustering that is period of relative tranquillity followed by periods of more turbulent volatility. This suggests we would need to control for heteroskedastic behaviour when modelling return and volatility. A final observation that is worth mentioning is that nearby crude oil futures contract series is more volatile than of most distant crude oil futures contract (4th nearest month contract) series.

Overall, Figure 4 and 5 suggest contemporaneous rise in S&P500 and crude oil futures price that arises the question of interconnectedness in their volatility and the directions of spillovers that may take place between these markets. In the next Section 4.3, we provide preliminary evidence of increasing volatility link between these markets and try to assess whether financialisation or liquidity are responsible for the level of increase.

4.3. Descriptive and Test Statistics

We compare the statistical properties of the data undertaken in this study using several summary statistics. As price series of S&P500 is non-stationary according to the Augmented-Dickey Fuller (ADF) and the Kwiatkowski–Phillips–Schmidt–Shin (KPSS) test, all return series are analysed by taking first log difference. Moreover, speculation index and open interest series are found to be non-stationary; thus, accordingly we take first difference of the series to make the series stationary.

Table 1: Descriptive Statistics

	Mean	Median	Max	Min	Std.Dev.	Skewness	Kurtosis	Jarque-Bera	ADF	KPSS	Q(10)	Q^2 (10)	ARCH-LM (10)	Obs.
Full Sample Period														
S&P500	0.0014	0.0036	0.1237	-0.1577	0.0224	-0.70 ***	8.07 ***	1622.28 ***	-11.05 ***	0.14 ***	28.28 ***	321.52 ***	157.92 ***	1407
Crude oil-01	0.0008	0.0031	0.2189	-0.2514	0.0493	-0.28 ***	4.74 ***	194.90 ***	-10.78 ***	0.07 ***	28.11 ***	276.30 ***	136.86 ***	1407
Crude oil-02	0.0008	0.0038	0.2171	-0.2349	0.0456	-0.28 ***	4.61 ***	170.23 ***	-10.84 ***	0.08 ***	24.92 ***	291.27 ***	139.35 ***	1407
Crude oil-03	0.0008	0.0038	0.2113	-0.2316	0.0431	-0.30 ***	4.80 ***	211.12 ***	-10.76 ***	0.09 ***	26.38 ***	290.14 ***	140.52 ***	1407
Crude oil-04	0.0008	0.0034	0.2036	-0.2191	0.0414	-0.28 ***	4.88 ***	226.48 ***	-10.69 ***	0.09 ***	29.58 ***	323.26 ***	150.75 ***	1407
Spec. Ind.	0.0002	0.0001	0.1260	-0.0833	0.0193	0.17 ***	6.54 ***	740.20 ***	-14.63 ***	0.01 ***	67.00 ***	229.56 ***	123.33 ***	1407
Open Int.	0.0013	0.0039	0.1379	-0.1528	0.0350	-0.42 ***	4.52 ***	177.01 ***	-11.54 ***	0.06 ***	603.75 ***	267.48 ***	147.26 ***	1407
Pre-Financialisation Period														
S&P500	0.0016	0.0035	0.1237	-0.1217	0.0240	-0.15	6.19 ***	244.35 ***	-6.37 ***	0.38	42.63 ***	175.98 ***	87.55 ***	573
Crude oil-01	0.0009	0.0019	0.1923	-0.2391	0.0502	-0.27 ***	4.63 ***	70.46 ***	-7.81 ***	0.06 ***	24.28 ***	27.00 ***	21.15	573
Crude oil-02	0.0009	0.0035	0.1842	-0.2349	0.0435	-0.38 ***	4.99 ***	108.32 ***	-7.76 ***	0.07 ***	21.19	18.10	15.87	573
Crude oil-03	0.0009	0.0032	0.1706	-0.2316	0.0397	-0.45 ***	5.54 ***	173.15 ***	-7.60 ***	0.08 ***	22.61	20.01	17.74	573
Crude oil-04	0.0008	0.0029	0.1535	-0.2191	0.0364	-0.47 ***	5.73 ***	198.79 ***	-7.46 ***	0.08 ***	24.01 ***	22.60	19.84	573
Spec. Ind.	0.0002	0.0007	0.1260	-0.0833	0.0257	0.18	4.72 ***	73.34 ***	-9.33 ***	0.01 ***	29.86 ***	30.40 ***	24.84 ***	573
Open Int.	0.0004	0.0025	0.0564	-0.0748	0.0197	-0.43 ***	3.55	25.22 ***	-8.40 ***	0.03 ***	285.24 ***	70.42 ***	50.43 ***	573
Post-Financialisation Period														
S&P500	0.0013	0.0038	0.0782	-0.1577	0.0213	-1.25 ***	9.89 ***	1865.68 ***	-8.97 ***	0.18 ***	16.69	165.03 ***	97.00 ***	834
Crude oil-01	0.0007	0.0036	0.2189	-0.2514	0.0488	-0.29 ***	4.81 ***	125.21 ***	-7.70 ***	0.14 ***	17.32	329.87 ***	131.08 ***	834
Crude oil-02	0.0008	0.0040	0.2171	-0.1712	0.0469	-0.22 ***	4.38 ***	73.09 ***	-7.80 ***	0.16 ***	14.72	350.41 ***	134.65 ***	834
Crude oil-03	0.0008	0.0042	0.2113	-0.1663	0.0454	-0.23 ***	4.40 ***	74.94 ***	-7.82 ***	0.18 ***	14.24	313.09 ***	128.04 ***	834
Crude oil-04	0.0008	0.0043	0.2036	-0.1651	0.0444	-0.20	4.41 ***	74.65 ***	-7.85 ***	0.20 ***	15.26	292.76 ***	121.29 ***	834
Spec. Ind.	0.0002	-0.0001	0.0557	-0.0522	0.0134	0.00	4.30 ***	58.40 ***	-10.91 ***	0.04 ***	58.67 ***	49.84 ***	41.61 ***	834
Open Int.	0.0018	0.0054	0.1379	-0.1528	0.0424	-0.40 ***	3.43	29.19 ***	-8.74 ***	0.06 ***	352.01 ***	34.49 ***	31.76 ***	834

Note:

This table presents descriptive statistics for weekly returns, speculative index and total open interest. The uppper, middle and lower panels show full sample, pre-financialisation period sample and post-financialisation period sample's descriptive statistics respectively. The null hypothesis of Jarque-Berra (J-B) test is returns are normally distributed. ADF reports the Augmented Dickey-Fuller statistics for the null hypothesis that there is a unit root in the variable. The null hypothesis of Kwiatkowski-Phillips-Schmidt-Shin (KPSS) test is the stationarity of returns. The null hypothesis of the Ljung–Box Q(LB-Q) test is returns are not autocorrelated. The null hypothesis of ARCH-LM test is the absence of ARCH effect.

[*] *** indicates the significance of reported statistics at 1% significance level.

Table 1 depicts descriptive statistics for weekly return series of S&P500 index, four consecutive crude oil futures contracts, speculation index and total open interest series for full sample, pre-financialisation and post-financialisation period. Mean returns are positive in all data sample. In all sample periods, nearby crude oil futures contract are the riskiest assets in terms of standard deviation. Moreover, in all sample periods, the standard deviation of crude oil futures decreases as maturity of the contract increases which is suggestive of Samuelson maturity effect in unconditional volatility. It is worth noting that during pre-financialisation period, nearby crude oil futures standard deviation is higher than standard deviation of financialisation period. For rest of the crude oil futures after financialisation standard deviation increases and volatility seems to be more stable among the futures contracts. In both pre- and post-financialisation periods, S&P500 index exhibits highest weekly return (0.16% and 0.13%)-risk (2.4% and 2.13%) ratio than crude oil futures return (ranges $0.07\% - .0.09\%$) and risk (ranges $3.6\% - 5.0\%$) due to diversification benefits. Skewness, adopted D'agostino (1970) is negative in all cases in return series, indicating that negative returns are more likely than positive returns. Kurtosis statistics adopted as Anscombe and Glynn (1983) is higher than 3 in all sample period in return series, indicating to presence of relatively peaked distribution and fat tails. Results from Jarque and Bera (1987)} test reject the normality of marginal distributions, that is the return series of equity index and crude oil futures distributions are leptokurtic indicating a higher peak and a fatter tail that of a normal distribution pointing towards the existence of conditional heteroscedasticity/ARCH effect (McLeod and Li 1983). Hence, we would need to account for autocorrelation in the series when analysing market integration.

Due to a dynamic conditional volatility process, an uncorrelated time series can still be serially dependant (Haixia and Shiping 2013). A time series that exhibits autocorrelation or conditional heteroscedasticity in the squared series are known as autoregressive conditional heteroscedastic (ARCH) effects. In general, there are two methods to examine ARCH effects of a series. Firstly, testing through Engle's ARCH- Lagrange multiplier (LM) test (Engle 1982) to examine the significance of ARCH effects. This is an usual F-statistic test for the regression on the squared series. The F-statistic follows χ^2 distribution with m degrees of freedom in the null hypothesis. We reject the null hypothesis when critical value is large. Secondly, testing to assess the ARCH effect is by conducting a Ljung Box-Q test. We examine the existence of conditional heteroscedasticity using ARCH Lagrange multiplier test. The test provide evidence of time varying volatility characterizations at 1% significance level and therefore, estimating a multivariate GARCH procedure seems to be appropriate in order to control for the presence of stylized facts, such as volatility clusters, fat tails, and persistence of equity index and crude oil futures return in the data. Besides, Ljung- Box portmanteau statistics for 20- lag length of return $Q(20)$ and squared return $Q^2(20)$ series exhibit serial correlation at 1% significance level indicating presence of temporal dependence in the series i.e. information regarding past return is relevant for return forecasting. Likewise, squared return series for evidence of significant autocorrelation can be explored through sample autocorrelation function (ACF) and partial autocorrelation function (PACF) in Appendix B.2 in Figure B.1 and B.2 respectively.

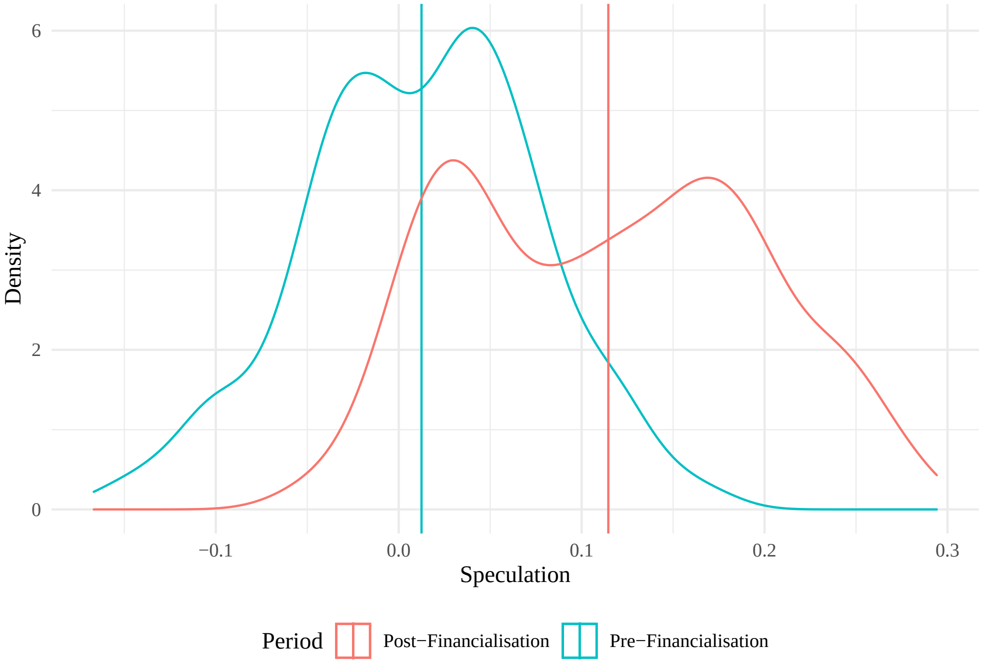

Figure 6: Distribution of Speculation Index of Crude Oil

In all sample, all log return series are stationary according to Augmented-Dickey Fuller (ADF) unit root tests as null hypothesis is rejected for all of return series when we chose the maximum lag zero and test without trend and intercept. Furthermore, Kwiatkowski–Phillips–Schmidt–Shin (KPSS) confirms the stationarity of the time series variables.

The positive mean of speculation index on all sample periods shows that on average speculators are net long, a result that is consistent with Bessembinder (1992). The mean of open interest in pre-financialisation period is 0.0004 whereas the value increases to 0.0018 after financialisation that is 3.5% growth. Moreover, the standard deviation of net speculator positions is positively related to the volatility of the crude oil futures contract at different maturity. The shape of the distributions of speculative activity and open interest are described using skewness and kurtosis. Negative skewness of open interest indicates that the probability distributions are negatively skewed whereas speculative index is found to be positively skewed. Kurtosis statistics reports that both speculative activity and open interest are statistically significant positive kurtosis that implies that their probability distribution have fat tails and high. The result on Table 1 indicates that the first difference of both speculation index and total open interest series are stationary at the conventional 1% level of significance. Moreover, the Jarque-Bera test statistics imply that the null hypothesis of normally distributed speculation index and open interest are rejected in every case at 1% significance level. Moreover, Kolmogorov-Smirnov (KS) test confirms that the distribution of speculation series differs between pre-and post-financialisation period.[18]

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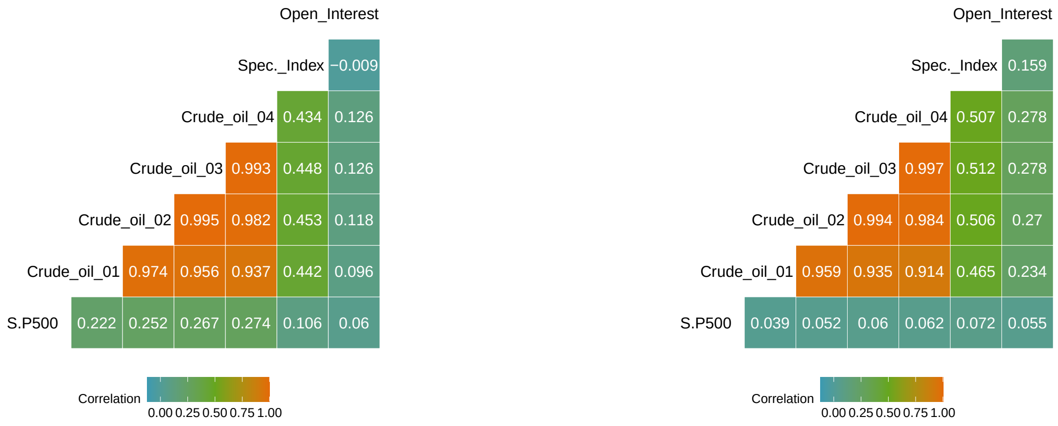
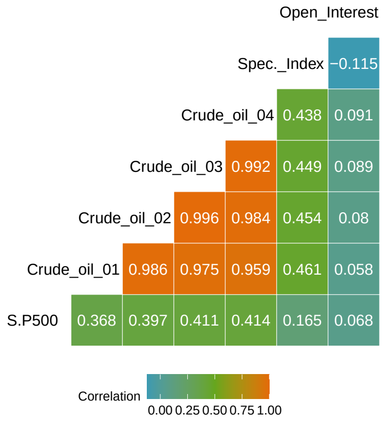
[18] D statistics= 0.1539 and p-value= $2.068e^{-}07$ where the null hypothesis is rejected at 95% confidence level which states there is no difference between the two distributions.



(a) Full sample period

(b) Pre-financialisation period



(c) Post- financialisation period

Figure 7: Unconditional correlation between variables

Figure 6 illustrates the distribution of speculative activity for crude oil futures during the pre-and-post financialisation period. Turquoise and red colour line represents pre-financialisation and post-financialisation period respectively and the vertical lines show mean of speculative activity for those two periods. During pre-financialisation period, majority of the index value ranges from approximately -0.1 to 0.1 whereas in the post financialisation period it ranges from approximately -0.075 to 0.25. The distribution of the speculation index exhibits shift to right when passing from pre financialisation period to post financialisation period. This implies an increase in speculative activity in the crude oil futures market. Moreover, the mean of pre-financialisation speculation is 0.013 which is lower than the mean of speculation during post-financialisation period of 0.115 which also confirms increase in speculative activity after 2004.

To obtain a *prima facie* measure on whether, and how, crude oil futures and equity markets are interconnected and how the assets volatility varies with speculative activity and open interest, we test unconditional correlation coefficients using heat maps to graphically illustrate the Pearson's correlation coefficient. We use orange colour to represent higher correlation where as mid range correlations are represented by green and low correlation in teal blue colour. The results in the Figure 7a illustrates the unconditional correlations between the equity crude oil futures market and speculative activity during full sample period. These correlation indicate that equity index return and crude oil returns are contemporaneously and positively correlation. Some of the lowest correlations of the equity and crude oil futures are with open interest. For instance, the correlations of open interest with equity index is only 6% and with nearby crude oil futures contract is 9.6%. Crude oil futures have relatively moderate correlations with speculation index, about 45% whereas equity index has much lower correlation with speculation index. In all sample periods, crude oil futures contracts have high correlations among them. Correlations between crude oil futures and equity index are between 22% − 27%. It is noticeable that the correlation starts to increase between crude oil futures and S&P500 index as crude oil futures have more distant maturity date. Speculative activity and open interest are negatively correlated for full sample period.

During pre-financialisation period in Figure 7b, speculation index and crude oil futures are moderately correlated. However, these correlations decrease after financialisation period. On the other hand, correlation of equity index and speculation increases after financialisation. While during pre-financialisation period correlation of crude oil futures and open interest was about 23% − 27%, after financialisation the correlation decreases to around 5% to 8%. Correlation between equity and open interest shows a bit increase after financialisation period (Figure 7c. Another interesting feature is that while the correlations between equity index and crude oil futures are positive for both pre-and-post financialisation, these correlations drastically increase after financialisation; for example, correlation between S&P500 index and nearby crude oil futures is only 3.9% during pre-financialisation period, whereas after financialisation the correlation increases to 36.8%. The fact that the observed correlation is higher between commodity and equity index is in line with the financialisation of commodity phenomenon (Girardi 2015; K. Tang and Xiong 2012, for example).

This findings, while preliminary, suggests that financialisation may increase overall level of volatility but stabilises volatility effect between futures contract at different maturities. The positive unconditional correlation between equity and speculation index, and open interest shows increases after financialisation period. In contrast, positive correlation between volatility of crude oil futures and speculation and open interest starts to decrease. The decreasing correlation between crude oil futures and speculation index suggest that financialisation represented by long term speculation may help to stabilise volatility by increasing liquidity in the market. The higher correlation between S&P500 and crude oil futures is the basis of the hypothesis on the financialisation tightening the interdependence between equity and commodity markets.

5. Empirical Results and Discussion

In Section 4, we demonstrate that a substantial change occurs due to financialisation of commodity markets. This development in the market shows both positive and negative consequences. However, so far no studies in empirical literature could confirm the destabilizing effect of financialisation on volatility or could confirm financialisation integrating both equity and commodity markets. Hence, in this section we present our findings to explain the determinants of equity and commodity price volatility and the intermarket dependences between these markets. We begin by presenting results of the estimated mean equation in Section 5.1.1. Section 5.1.2 describes on variance part of the model. The integration between the equity and crude oil markets are described in Section 5.1.3. Section 5.1.4 discusses the results of two sample periods illustrating the changing nature of correlation between these markets. Various relationship between variables are discussed in Section 5.1.5. Section 5.1.6 explains visible maturity effect and Samuelson correlation effect during pre- and post-financialisation period. Role of financialisation and liquidity on changing volatility and integration are reported in Section 5.2 and finally Section 5.2.2 demonstrates the causality between financialisation, liquidity and price volatility, market integration. The subsections are structured as following style: First, a brief description of results and some interesting findings are noted. Then, a discussion of the results is presented and compared with the findings of other related empirical literatures.

5.1. Impact of Financialisation by Sub-Period Analysis

5.1.1. Mean Estimates

The mean estimation of the model is presented in Table 2. In pre-financialisation period, we find S&P500 index return is affected by its' own lag which is consistent with findings of Vo (2011) although the effect is not found for post financialisation period. The correlation coefficient is negative that indicates mean reverting behaviour of returns, however, the influence is quite weak but statistically significant. This result is in line with the findings of Junttila, Pesonen, and Raatikainen (2018) that shows negative correlation coefficient on the lagged S&P500 return observations while doing analysis on correlation between crude oil futures, gold futures and equity markets. Since financialisation, S&P500 return is affected by the lag of nearby crude oil futures return that is 1st crude oil futures return have positive spillover on S&P500 index return. This relationship is found to be positive; for instance, when nearby crude oil futures returns increases by 1%, S&P500 index return increases 0.31% ($\psi_{S\&P500,CL01}$) in the next week for post-financialisation period (other things being unchanged). These coefficients also indicate that the crude oil futures returns, and the S&P500 index returns show unidirectional causality, which is justifiable because oil sector benefit from increase in crude oil prices. However, during pre-financialisation period, S&P500 index return is not influenced by any crude oil futures return lag. Moreover, in both periods, crude oil market investors do not necessarily make choice of investment decision relying on past financial shock information. Additionally, nearby crude oil futures contract is affected by its' own lag ψ_{CL01}. Notably, while the relationship is negative before financialisation period, this significant relationship changes to positive after financialisation period which indicates commodity futures return to become more correlated since financialisation of commodities.

Table 2: DCC GARCH Results for Mean Equation

	S&P500	Crude oil 01	Crude oil 02	Crude oil 03	Crude oil 04
Pre-Financialisation Period					
S&P500-l1	-0.1458155***	0.0344930	0.0378009	0.0398834	0.0408791
	0.0413421	0.0867338	0.0759145	0.0692967	0.0635288
Crude oil 01-l1	0.0593547	-0.6740616***	-0.2020861	-0.1637551	-0.1276112
	(0.0874468)	(0.1834594)	(0.1605744)	(0.1465764)	(0.1343761)
Crude oil 02-l1	0.1402803	1.0833799	0.0926496	0.1803621	0.0005479
	(0.4063009)	(0.8524009)	(0.7460714)	(0.6810329)	(0.6243472)
Crude oil 03-l1	-0.1200609	0.8478636	1.5694125	1.2243480	1.5311588
	(0.8067087)	(1.6924383)	(1.4813214)	(1.3521878)	(1.2396387)
Crude oil 04-l1	-0.1877704	-1.4956924	-1.6822744*	-1.4418358	-1.5991071**
	(0.5306576)	(1.1132956)	(0.9744217)	(0.8894769)	(0.8154414)
Const	0.0035863*	0.0045054	0.0049041	0.0049754	0.0049919
	(0.0019764)	(0.0041464)	(0.0036292)	(0.0033128)	(0.0030371)
Winter	-0.0018155	-0.0027146	-0.0038181	-0.0042853	-0.0045518
	(0.002812)	(0.0058994)	(0.0051635)	(0.0047133)	(0.004321)
Summer	-0.0026627	-0.0026813	-0.0031960	-0.0031360	-0.0032177
	(0.0027798)	(0.0058319)	(0.0051044)	(0.0046594)	(0.0042716)
Fall	-0.0020232	-0.0082318	-0.0084545*	-0.0085917*	-0.0085189**
	(0.0027946)	(0.0058629)	(0.0051316)	(0.0046842)	(0.0042943)
Post-Financialisation Period					
S&P500-l1	-0.0135253	0.0781110	0.1128792	0.1131264	0.1075274
	0.0384105	0.0880273	0.0841046	0.0814728	0.0798351
Crude oil 01-l1	0.3180791***	0.5440197**	0.8233399***	0.6627087***	0.6208402***
	(0.1053566)	(0.2414514)	(0.2306916)	(0.2234728)	(0.2189807)
Crude oil 02-l1	-0.3103304	-0.1793994	-0.3234453	-0.0173499	-0.2521018
	(0.3063959)	(0.7021838)	(0.6708924)	(0.6498989)	(0.6368352)
Crude oil 03-l1	-0.0692073	-0.6010101	-0.7607633	-0.8642122	-0.0825893
	(0.3248601)	(0.7444991)	(0.711322)	(0.6890633)	(0.6752124)
Crude oil 04-l1	0.0403235	0.1561919	0.1873721	0.1521224	-0.3475910
	(0.1437256)	(0.3293836)	(0.3147053)	(0.3048576)	(0.2987296)
Const	0.0019340	0.0072563**	0.0063192**	0.0058072*	0.0054056*
	(0.0014652)	(0.0033579)	(0.0032083)	(0.0031079)	(0.0030454)
Winter	0.0000651	-0.0068136	-0.0053138	-0.0046029	-0.0040389
	(0.0020952)	(0.0048016)	(0.0045876)	(0.0044441)	(0.0043547)
Summer	-0.0020538	-0.0081238*	-0.0073880	-0.0067856	-0.0062576
	(0.0020695)	(0.0047428)	(0.0045314)	(0.0043896)	(0.0043014)

(Continued on next page...)

Table 2: DCC GARCH Results for Mean Equation *(continued)*

	S&P500	Crude oil 01	Crude oil 02	Crude oil 03	Crude oil 04
Fall	-0.0005618	-0.0114400**	-0.0100459**	-0.0092827**	-0.0086865**
	(0.0020791)	(0.0047647)	(0.0045524)	(0.0044099)	(0.0043213)

Note:

This table presents mean part of VAR estimates for pre-financialisation period and post-financialisation period sample's descriptive statistics respectively. The mean equation is $r_t = \mu_t + \Phi r_{t-1} + \Psi d_t + \varepsilon_t$ where $\mu_t, r_{t-1}, d_t, \varepsilon_t$ represents constant term, return at time $(t-1)$, seasonal dummy for Winter, Summer and Fall and residuals for return series respectively. Figures in the parenthesis represent standard error.l1 represents lag 1 that is at time $(t-1)$.

[*] ***,** and * denote statistical significance at 1%, 5%, and 10% level.

The evidence of seasonal effect is mixed in both sample period. Before financialisation period, the parameters of fall (Φ^{fall}) coefficients to be significant at level 10% and 5% respectively for 2$^{\text{nd}}$ to 4$^{\text{th}}$ crude oil futures contract. However, these relationships are negatively correlated. As expected, we do not find any seasonal effect in equity market return. Since financialisation, mean return exhibits significant fall seasonality for all crude oil futures return. This implies that in fall usually there is a lower return *ceteris paribus*, from the crude oil futures contract. As our main focus is on variance part of the model, we do not go into further details of mean estimates result. Overall, the VARX process features the statistical significance of the equity and crude oil futures market price dynamics. Additionally, it also provides insight on time-varying integration of equity and crude oil futures market that could be initiated by the financialisation of commodity markets.

Table 3: Mean, ARCH effect, autocorrelation, normality test results of VARX residuals

	Mean	Skewness	Kurtosis	Jarque-Bera	Weighted-box	$Q(10)$	$Q^{2}(10)$	ARCH-LM (10)
Pre-Financialisation Period								
S&P500	-2e-05	-0.35 ***	5.61 ***	174.53 ***	13.11	22.98	151.29 ***	74.28 ***
Crude oil-01	-9e-05	-0.30 ***	4.46 ***	60.05 ***	12.64	17.65	20.49	17.09
Crude oil-02	-8e-05	-0.37 ***	4.64 ***	77.32 ***	9.17	15.18	17.27	15.23
Crude oil-03	-8e-05	-0.43 ***	5.09 ***	121.51 ***	9.71	16.61	17.88	15.78
Crude oil-04	-7e-05	-0.44 ***	5.20 ***	133.73 ***	10.29	17.91	20.22	17.65
Post-Financialisation Period								
S&P500	1e-05	-1.30 ***	10.01 ***	1940.07 ***	7.50	16.30	123.29 ***	76.18 ***
Crude oil-01	2e-05	-0.28 ***	4.73 ***	114.88 ***	4.09	15.22	255.75 ***	116.92 ***
Crude oil-02	3e-05	-0.17	4.50 ***	82.19 ***	3.77	12.07	194.43 ***	95.03 ***
Crude oil-03	4e-05	-0.16	4.49 ***	80.95 ***	3.89	11.56	192.67 ***	95.40 ***
Crude oil-04	3e-05	-0.14	4.45 ***	76.27 ***	4.49	11.72	195.79 ***	96.66 ***

Note:

This table presents descriptive statistics for residuals of VARX process.The uppper middle and lower panels show pre-financialisation period and post-financialisation period sample's descriptive statistics respectively. The null hypothesis of Jarque-Berra (J-B) test is returns are normally distributed. The null hypothesis of the Ljung–Box Q(LB-Q) test is returns are not autocorrelated. Weighted Box-Pierce test is used to detect nonlinear effects in the residuals. The null hypothesis of ARCH-LM test is the absence of ARCH effect.

[*] *** indicates the significance of reported statistics at 1% significance level.

5.1.2. Variance Estimates

Table 4 reports the results of volatility models which is the central point of this paper. In both periods, the parameters α are all statistically significant at the 1% level for S&P500 index and for all crude oil futures. The parameters α, that quantifies the short term volatility persistence range from $0.111662 - 0.1156642$ for the S&P500 Index and $0.0206603 - 0.0960216$ for crude oil futures contract. The ARCH effect (α) of crude oil futures are lower in pre-financialisation period than of post financialisation period. As expected, we find in both pre-and-post financialisation period, ARCH effect to lowering as maturity of crude oil futures increases until it reaches to the most distant crude oil futures contract; interestingly, when the ARCH effect is found to be a bit higher than distant contract but still lower than the front month contract. We also find parameters β are significant at the 1% level in both market representing volatility sensitivity of their own past conditional volatilities. These βs' range from $0.8569824 - 0.8789884$ for the S&P500 Index and $0.8741033 - 0.9789662$ to for crude oil futures. In all cases ARCH effect is lower than GARCH effect, implying that past variances are dominant over current variances. This indicates that conditional volatility series do not change abruptly rather it evolves steadily over a long horizon depending on the past volatility. The sum of the coefficients of $\alpha + \beta$ is close to unity, which depicts that a shock to volatility in both equity and crude oil futures market are quite stable. However, as $\alpha + \beta < 1$ for all asset represents sufficient condition for consistency and asymptotic normality of the QMLE estimator (McAleer, Chan, and Marinova 2007).

Table 4: Estimates of variance equation of VARX DCC GARCH

	S&P500	Crude Oil 01	Crude Oil 02	Crude Oil 03	Crude Oil 04
Pre-Financialisation Period					
Constant	0.0000060***	0.0000705	0.0000040**	0.0000000	0.0000000
	2e-06	2e-06	2e-06	2e-06	2e-06
ARCH	0.1156642***	0.0467262	0.0206603***	0.0224417***	0.0230685***
	(0.007545)	(0.007545)	(0.007545)	(0.007545)	(0.007545)
GARCH	0.8789884***	0.9260494	0.9789662***	0.9750881***	0.9746524***
	(0.0079696)	(0.0079696)	(0.0079696)	(0.0079696)	(0.0079696)
Winter	0.0000000	0.0000001	0.0000006	0.0000163	0.0000064
	(3.3e-06)	(3.3e-06)	(3.3e-06)	(3.3e-06)	(3.3e-06)
Summer	0.0000000	0.0000000	0.0000000	0.0000000	0.0000001
	(1.11e-05)	(1.11e-05)	(1.11e-05)	(1.11e-05)	(1.11e-05)
Fall	0.0000000	0.0000000	0.0000000	0.0000104	0.0000152***
	(2.6e-06)	(2.6e-06)	(2.6e-06)	(2.6e-06)	(2.6e-06)
Statistics	likelihood	Akaike	Bayes	Lambda 1	Lambda 2
stat	9507.5682631	-32.8780742	-32.2098754	0.0467868***	0.8905700***
Post-Financialisation Period					
Constant	0.0000156***	0.0000709	0.0000650	0.0000632	0.0000615

(Continued on next page...)

Table 4: Estimates of variance equation of VARX DCC GARCH *(continued)*

	S&P500	Crude Oil 01	Crude Oil 02	Crude Oil 03	Crude Oil 04
	3e-07	3e-07	3e-07	3e-07	3e-07
ARCH	0.1116627***	0.0960216***	0.0939680***	0.0951791**	0.0996120***
	(0.0111332)	(0.0111332)	(0.0111332)	(0.0111332)	(0.0111332)
GARCH	0.8569824***	0.8741033***	0.8765573***	0.8743518***	0.8698481***
	(0.0195569)	(0.0195569)	(0.0195569)	(0.0195569)	(0.0195569)
Winter	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
	(2e-07)	(2e-07)	(2e-07)	(2e-07)	(2e-07)
Summer	0.0000022	0.0000000	0.0000000	0.0000000	0.0000000
	(2.8e-06)	(2.8e-06)	(2.8e-06)	(2.8e-06)	(2.8e-06)
Fall	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
	(2.7e-06)	(2.7e-06)	(2.7e-06)	(2.7e-06)	(2.7e-06)
Statistics	likelihood	Akaike	Bayes	Lambda 1	Lambda 2
stat	15313.9523491	-36.5569084	-36.0577452	0.0893594***	0.9073588***

Note:

This table presents variance part and statistics of DCC GARCH estimates for pre-financialisation period sample and post-financialisation period. Conditional variance is $h_t = \omega + A\varepsilon_{t-1}^2 + Bh_{t-1} + \gamma d_t$ where $\omega, \varepsilon_{t-1}^2, h_{t-1}$ and d_t represents constant term, short term persistence, long term persistence and seasonal dummy for Winter, Summer and Fall season respectively. Figures in the parenthesis represent standard error.

* ***,** and * denote statistical significance at 1%, 5%, and 10% level.

In terms of seasonal effect, we do not find any significant seasonal effect in volatility of S&P500 index for any sample period. Before financialisation period, most distant crude oil futures contract (4th) exhibits positive significant fall seasonality. This indicates volatility of (4th) crude oil futures is affected more during fall compared to other seasons. This is due to the fact that WTI crude oil prices are in yearly peak during early fall. As the winter nears the price starts to settle in yearly lows. However, the coefficient shows that the seasonal effect is very weak. As hypothesised, we find the fall seasonality to be insignificantly different than zero for most distant crude oil futures contract after financialisation period. As explained in Section 2, this may be due to the fact that financialisation of commodity market diminishes the seasonality effect. As equity market is larger than crude oil futures market, through financialisation process, the equity markets tend to influence more crude oil markets than the other way round. Thus, crude oil futures looses the commonly observed seasonal pattern in volatility and acts more like a financial asset. Our findings is similar to Yu and Ryu (2020) only difference is that mentioned paper focuses on effect of ETN's announcement on volatility of seasonal component. Overall we can say that financialisation weakens the seasonal pattern in volatility of crude oil futures.

In both period, the parameters θ_1 and θ_2, that is related with the short run and long run persistence of shocks on the dynamic conditional correlation, are statistically significant at 1% level across all GARCH models. This implies conditional correlation are time-varying. Only exception is noted in nearby crude oil futures during pre-financialisation period. Additionally, $\theta_2 > \theta_1$ that indicates long run persistent volatility spillover between equity and crude oil market returns.

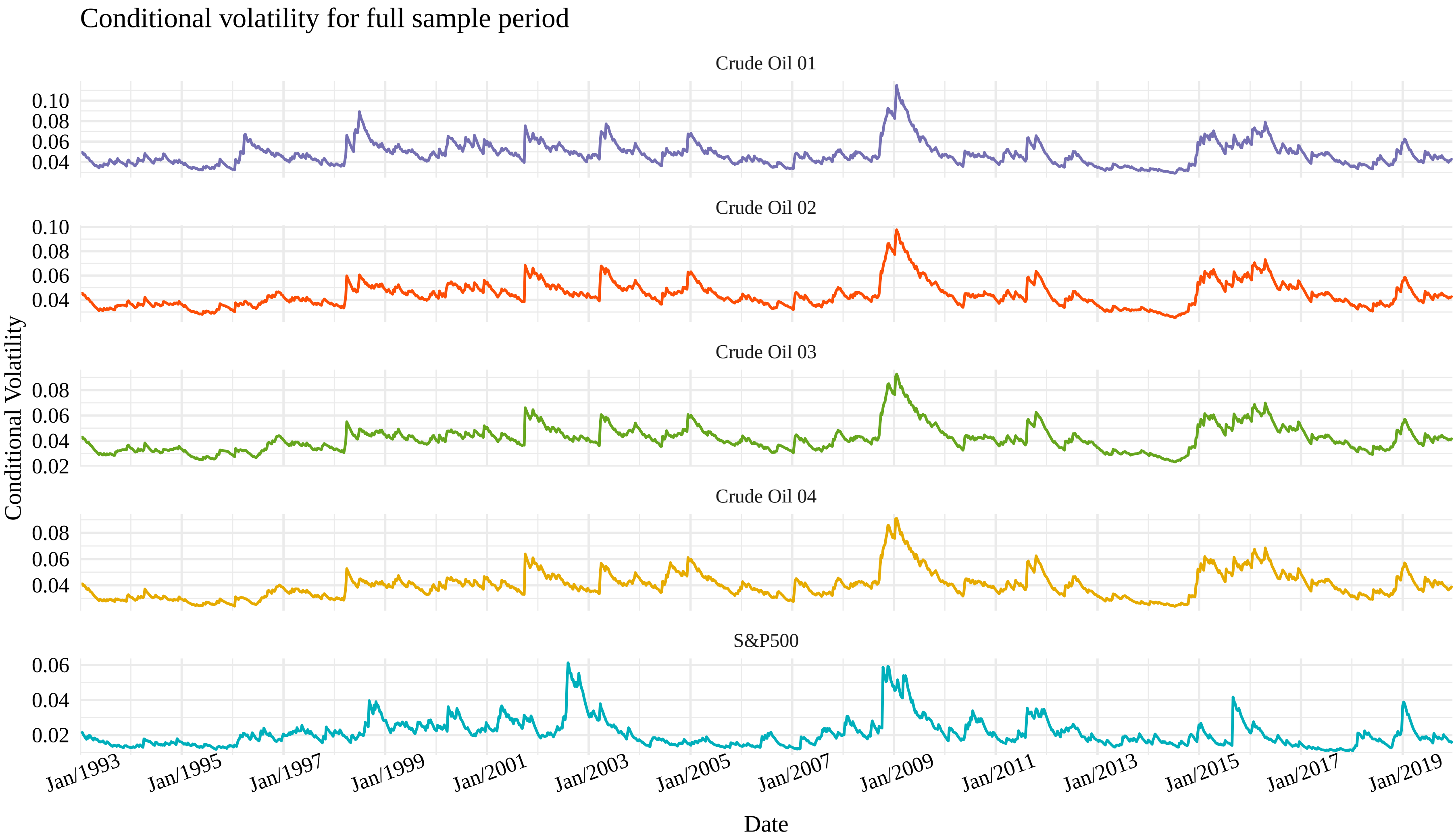


Figure 8: Conditional volatility for full sample period

Figure 8 shows conditional volatility retrieved from VAR-DCC-GARCH model for the full sample period. There are some noticeable peaks in equity index conditional volatility around mid 2001, 2008, 2014 which corresponds for various economic events. Crude oil futures market is observed to be more volatile than equity market. Especially, since 2004 there is more volatility noticed in all crude oil futures series.

5.1.3. Market Interdependence

To understand the pattern of volatility spillover from commodity markets to equity markets, we estimate the correlation between equity markets and the respective crude oil futures market. Figure 9 plots the dynamic conditional correlations (DCC) between equity index and crude oil futures contract at various maturity. We find that the DCC model with no lag and seasonality component presents an increase level of volatility.[19] Hence, the lower level of the DCC model can be explained by inclusion of seasonality and VAR component.

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[19] These results are available on request.

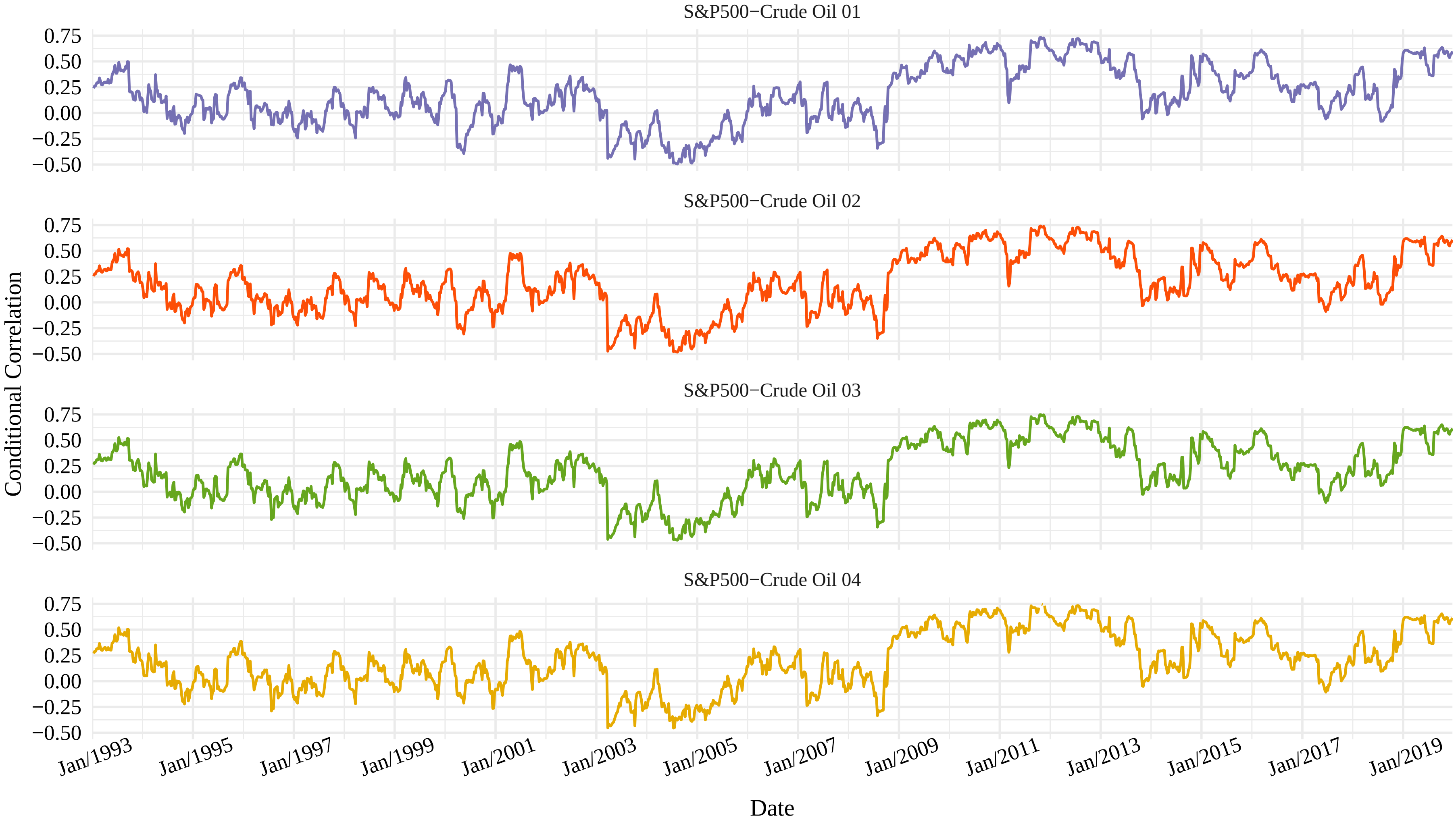

Figure 9: Conditional correlation for full sample period

The correlation has changed widely during different periods in the last two decades which is consistent with earlier evidence. The interdependence between equity and crude oil significantly varies over the full sample period and ranges between -0.4954254 to 0.7521605. However, once we divide the sample into the pre-financialisation and post-financialisation periods, the correlations change, indicating a development in the relationship between equity and crude oil futures markets. The commodity-equity correlations is not stable over the whole sample period (The DCC of all crude oil futures have almost the similar movements). For crude oil futures and S&P500 index, the correlation ranges between -0.3552094 to 0.3182922 during pre-financialisation period where as during post-financialisation period it ranges between -0.567964 to 0.7915093. This correlation varies more in financialisation period than of pre-financialisation period. Overall during pre-financialisation period, the correlation is observed to be lower which indicates low intrusion of financial investors in these markets. In between 2002-2004 period, the correlation was negative throughout the period and by the end of 2004 it reached to -0.38. Particularly, in 2002 there a substantial drop in correlation which is due to IT bubble in 2001. Since 2004, the correlation starts to increases and remains more or less at similar level indicating development of similarities in increasing price dynamics between equity and crude oil futures market. These conclusions, although generated in a complex econometric framework of multivariate GARCH model and measured in a different scale, could also be drawn from simple framework of unconditional correlation in Figure 7 in Section 4.3; which also suggests higher correlation between crude oil futures and equity markets since financialisation.

Interestingly, after the collapse of Lehman Brothers in 2008, the correlation jumped to over 0.6. This finding of dynamic conditional correlation for crude oil futures is consistent with (Büyükşahin, Haigh, and Robe 2010). Creti, Joëts, and Mignon (2013) suggests that the initial decline in correlations during financialisation period could be due to flight to quality or flight to liquidity .[20] Whereas Filis, Degiannakis, and Floros (2011) explains this rise in correlation could be due to shock in aggregate demand. Moreover, he states the recession resulting from the GFC causes drop in oil price, and can lead to increase in the correlation. Similarly, Szafranek (2015) explains this behaviour as herding behaviour of financial agents induced by financial crisis as everyone heading to the exit at the same time. This correlation remains at higher level till the end of sample period with some interruption by episodes of negative correlations in 2011 and 2013. This high correlation between commodity and equity market is contrary to theoretical perspectives and therefore, presents evidence against theories. These findings are consistent with studies investigating the link between the S&P500 index and energy commodities such as (Filis, Degiannakis, and Floros 2011; Creti, Joëts, and Mignon 2013; Kolodzeij and Kaufmann 2014). Junttila, Pesonen, and Raatikainen (2018) explains this market dependencies due to low convenience yield and low interest rate that attract investors, especially institutional investors to invest in commodity futures market rather than physical crude oil. It appears to be a natural ascertainment that the financialisation of commodity markets significantly affected the price dynamics

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[20] i.e. while concerns about risk reduce liquidity in general, investors are likely to substitute safe-haven assets, for risky assets when uncertainty is high and their risk tolerance is low.

on the commodity markets and, in fact, explains a strong increase in intermarket connectedness.

In 2011, there is a drop in correlation which could be due to that fact the investors trying to lower their risk and starts to invest in commodities as asset class. Szafranek (2015) suggests the drop in interdependency may be due to the result of the Dodd-Frank Wall Street Reform and Consumer Protection Act (henceforth, Dodd-Frank Act) introduced in 2010 that leads to some momentous changes to financial regulation of the commodity markets.[21]. In 2013, the correlation falls significantly and starts to increase in late 2014 that corresponds with Junttila, Pesonen, and Raatikainen (2018).

Relying on the empirical evidence of Büyükşahin and Robe (2014), especially the activity of traders who trade both equities and crude oil increases the cross-market linkage in the rates of returns of equities and crude oil futures. Hence, in contango market, these traders are more likely to increase their positions in crude oil. The hypothesis on net long positions of the trader during the period are tested in Granger Causality test in Section 5.2.2. Moreover, the higher correlation between equity and crude oil futures markets suggests greater interdependence between these markets, implying potentially greater spillover from one market to another. However, the correlation might not provide a definitive answer on the directional spillover from one market to another; therefore, further analyses to be tested for our future research to ascertain such interaction between financial and commodity markets.

5.1.4. Sensitivity Over Time

We test whether the mean of dynamic conditional correlation varies from pre financialisation period to post-financialisation period as Manera, Nicolini, and Vignati (2013a). Table C.2 in Appendix C.3 shows mean tests on dynamic conditional correlations during the pre-and-post financialisation period. We find all t-statistics are significant at 1% level except for correlations between distant crude oil futures and most distant crude oil futures. The result implies that all mean values of ρ are different during pre and post financialisation. Particularly, the mean values between equity index and crude oil futures are much higher after financialisation than of before financialisation period. This result confirms that there is increasing connection between equity and crude oil futures market. Moreover, dynamic conditional correlation among assets with different maturity increases after financialisation.

5.1.5. Various Linkages of Variables

In this section, we investigate financialisation process in relation with conditional volatility and conditional correlation results obtained from DCC GARCH model. Figures B.3 and B.4 in Appendix B.2 show various correlation and density function between conditional volatility, conditional correlation, speculation index and open interest

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[21] Dodd- Frank Act was initiated to promote transparency in market and to restrict excessive speculation in energy derivatives market. In section 737 of the act on position limit, CFTC proposed regulations to maximise practicability (i) to to diminish, eliminate, or prevent excessive speculation described as "causing sudden or unreasonable fluctuations or unwarranted changes in the price of such a commodity"; (ii) to deter and prevent market manipulation, squeezes, and corners; (iii) to ensure sufficient market liquidity for bona fide hedgers; and (iv) to ensure that the price discovery function of the underlying market is not disrupted. More details of the act is available on https://www.govinfo.gov/content/pkg/PLAW-111publ203/html/PLAW-111publ203.htm

for both pre-and-post financialisation period. Overall, Figures B.3 and B.4 show how correlation between these variables has evolved since the financialisation.

5.1.5.1. Long Run Risks. This section set out with the aim of assessing the relationship between the conditional volatility and conditional correlations between S&P500 index and crude oil futures to investigate whether financialisation is leading to higher integration of these markets and whether benefits of diversification is reduced. It is hypothesised that since financialisation, the extent of volatility is increased and equity being larger market will have more have in the link between crude oil futures and equities. Table 5 documents such evidence through the regression by using Equation (10).

We find overall, less significant impact of volatility on correlation between equity and crude oil futures during pre-financialisation period whereas more statistically significant results are found for post financialisation period. During pre-financialisation period, negative and statistically significant coefficients for change in conditional volatility of equity market are found for the pair S&P500 and front month and next nearby Crude oil futures contract (-2.52 and -1.73, respectively) that suggests correlations are stronger in the period of low changing stock market volatility. Likewise, during low period of volatility of distant crude oil futures, correlations of all the pairs are strong. Interestingly, positive and statistically significant coefficients $(42.07, 41.26, 44.10, 43.19)$ are found for most distant crude oil futures contract (4th) which indicates correlations are higher when change in volatility is higher.

During financialisation period, ξ_1 for S&P500 and ξ_2 and ξ_4 for front month and distant crude oil futures are found to be positive and statistically significant while ξ_3 for next nearby crude oil contract are found to be negative. This suggests during extreme change in volatility episode correlations grow higher for all pairs except for next nearby contract (2nd) which shows opposite effect. Closer inspection of the regression shows that the impact of volatility of S&P500 on correlation increases $(6.40, 7.07, 7.76$ and $8.13)$ as maturity of the crude oil contract increases from 1st to 4th consecutively. The change in coefficient of volatility of most distant contract (ξ_5) is insignificant during financialisation period which indicates, volatility of the contract loses its' explanatory power when enters financialisation period. Overall, sensitivity to change in equity market volatility is observed during financialisation period. A possible explanation for this might be that stock market is related with crude oil futures market for any maturity as impact of stock market varies depending on cost of production and earnings of the company. Altogether the results indicate closer integration between equity markets and crude oil futures markets. These results are reflect to those of Demiralay and Ulusoy (2014), who also find higher linkage among some commodity indices and stock markets during volatile period.

A comparison of two sample period reveals the role of financialisation on intensifying integration between crude oil futures and equity markets. Consequently, this suggests, during the periods of higher volatility, there may be deteriorating effects of diversification benefits. In particular, volatility of equity market impacts more on the linkage between equity and commodity since the financialisation indicating towards our hypothesis to be true.

Table 5: Regression Results

	Dependent variable:							
	pre-financialisation period				financialisation period			
	ρ *S&P500-CLF01*	ρ *S&P500-CLF02*	ρ *S&P500-CLF03*	ρ *S&P500-CLF04*	ρ *S&P500-CLF01*	ρ *S&P500-CLF02*	ρ *S&P500-CLF03*	ρ *S&P500-CLF04*
$\xi_1 h_{S\&P500}$	-2.52^{**}	-1.73^{*}	-1.59	-1.42	6.40^{***}	7.07^{***}	7.76^{***}	8.13^{***}
	(0.98)	(0.99)	(0.99)	(0.99)	(1.16)	(1.16)	(1.17)	(1.17)
$\xi_2 h_{CLF01}$	1.89	1.01	0.95	0.60	14.20^{***}	13.61^{***}	13.35^{***}	12.65^{***}
	(2.43)	(2.44)	(2.44)	(2.43)	(4.47)	(4.48)	(4.50)	(4.50)
$\xi_3 h_{CLF02}$	4.16	9.41	7.08	6.81	-76.05^{***}	-73.34^{***}	-69.67^{***}	-62.58^{***}
	(15.27)	(15.34)	(15.37)	(15.33)	(13.43)	(13.47)	(13.52)	(13.53)
$\xi_4 h_{CLF03}$	-44.90^{*}	-47.08^{*}	-47.75^{*}	-45.60^{*}	67.24^{***}	63.82^{***}	59.12^{***}	46.20^{***}
	(24.95)	(25.06)	(25.10)	(25.03)	(14.48)	(14.52)	(14.57)	(14.58)
$\xi_5 h_{CLF04}$	42.07^{**}	41.26^{**}	44.10^{**}	43.19^{**}	-3.32	-2.39	-1.47	4.72
	(19.85)	(19.94)	(19.97)	(19.91)	(6.44)	(6.46)	(6.48)	(6.48)
ξ_0	-0.0004	-0.0004	-0.0004	-0.0004	0.001	0.001	0.001	0.001
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Observations	572	572	572	572	833	833	833	833
R^2	0.02	0.02	0.01	0.01	0.12	0.12	0.12	0.12
Adjusted R^2	0.01	0.01	0.01	0.01	0.11	0.11	0.11	0.11

Note: The table reports estimated results from the regression: $\rho_{ij,t} = \xi_0 + \xi_1 h_{i,t} + \sum_{t=1}^{4} \xi_2 h_{j,t} + \vartheta_{ij,t}$ that examines the relationship between conditional correlation and conditional volatility for pre-financialisation and during financialisation period. $\vartheta_{ij,t}$ is standardised error term shown in parentheses. ξ_0, ξ, h, ρ and CLF represents constant term, coefficients of independent variables, conditional volatility, time varying correlation and crude oil futures contract respectively. **,* and * denote statistical significance at 1%, 5%, and 10% level.

5.1.5.2. Link between Time-varying Volatility of Equity and Crude Oil Futures. We analyse how the volatility of the crude oil futures against volatility of the equity market varies depending on financialisation. Figures B.5 and B.6 show such relation during pre-financialisation and post financialisation period respectively. Before financialisation period, the volatility correlation is found lower whereas the correlation between their volatility gets much higher after financialisation period.

To explore whether crude oil futures volatility is impacted by the volatility of S&P500, we perform regression analysis. The results are shown in Table 6. We find insignificant results for pre financialisation period, in both cases whether volatility of equities affected by volatility of crude oil futures or the other way round. However, we find significant coefficients for equities' volatility effecting crude oil futures volatility and vice-versa which suggests bidirectional effect during financialisation period. In particular we find the impact of volatility of equity increases the volatility of the crude oil futures as the maturity of the contract increases. As shown in Table 6, coefficient Ξ_1 of $h_{S\&P500}$ increases $(0.026, 0.027, 0.029$ and $0.032)$ significantly as maturity of the contract increases from 1st to 4th consecutively since the financialisation.

Table 6: Regression Results

	Dependent variable:							
	pre-financialisation period				financialisation period			
	h_{CLF01}	h_{CLF02}	h_{CLF03}	h_{CLF04}	h_{CLF01}	h_{CLF02}	h_{CLF03}	h_{CLF04}
$\Xi_1 h_{S\&P500}$	0.04	0.02	0.01	0.01	0.26^{***}	0.27^{***}	0.29^{***}	0.32^{***}
	(0.04)	(0.02)	(0.02)	(0.02)	(0.05)	(0.05)	(0.05)	(0.05)
Ξ_0	0.0000	0.0000	0.0000	0.0000	−0.0000	−0.0000	−0.0000	−0.0000
	(0.0001)	(0.0000)	(0.0000)	(0.0000)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
Observations	572	572	572	572	833	833	833	833
R^2	0.002	0.002	0.001	0.001	0.03	0.03	0.04	0.05
Adjusted R^2	-0.0002	-0.0001	-0.001	-0.001	0.03	0.03	0.04	0.05

Note: The table reports estimated results from the regression: $h_{j,t} = \Xi_0 + \Xi_1 h_{S\&P500} + \vartheta_{i,t}$ that examines how conditional volatility of equities impacts on conditional volatility of commodity futures during pre-financialisation and financialisation period. Standard errors $\vartheta_{i,t}$ in parentheses. Ξ, h and CLF represents coefficient of equities' conditional volatility, conditional volatility and crude oil futures contract respectively.***,** and * denote statistical significance at 1%, 5%, and 10% level.

In order to assess whether the volatility of equities is affected by the volatility of crude oil futures we also perform regression analysis. These results are shown in Table 7. No significant correlation is found on volatility of crude oil futures impacting on the volatility of equities before financialisation period. On the contrary, after financialisation, we find positively increasing (ranges from 0.11 to 0.15) coefficients $(\Upsilon_1, \Upsilon_2, \Upsilon_3, \Upsilon_4)$ of crude oil futures impacting on volatility of equities. Interestingly, volatility of deferred contract has more impact on volatility of equities.

To conclude this section, the study identifies some drastic change in impact of volatilities on crude oil futures and equities on each other depending on the sample period. Since financialisation, we find that both market can impact on each other's volatility to change. The result supports the hypothesis that price volatility transmits from equities to crude oil futures markets. In particular, we find some evidence on volatility pattern on commodity futures market. In the next section, that follows, we look into these patterns thoroughly by using various tests.

Table 7: Regression Results

	Dependent variable:							
	pre financialisation period				financialisation period			
	$h_{S\&P500}$	$h_{S\&P500}$	$h_{S\&P500}$	$h_{S\&P500}$	$h_{S\&P500}$	$h_{S\&P500}$	$h_{S\&P500}$	$h_{S\&P500}$
$\Upsilon_1 h_{CLF01}$	0.04				0.11^{***}			
	(0.04)				(0.02)			
$\Upsilon_2 h_{CLF02}$		0.10				0.13^{***}		
		(0.11)				(0.02)		
$\Upsilon_3 h_{CLF03}$			0.07				0.15^{***}	
			(0.10)				(0.02)	
$\Upsilon_4 h_{CLF04}$				0.06				0.15^{***}
				(0.11)				(0.02)
Υ_0	−0.0000	−0.0000	−0.0000	−0.0000	−0.0000	−0.0000	−0.0000	−0.0000
	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
Observations	572	572	572	572	833	833	833	833
R^2	0.002	0.002	0.001	0.001	0.03	0.03	0.04	0.05
Adjusted R^2	-0.0002	-0.0001	-0.001	-0.001	0.03	0.03	0.04	0.05

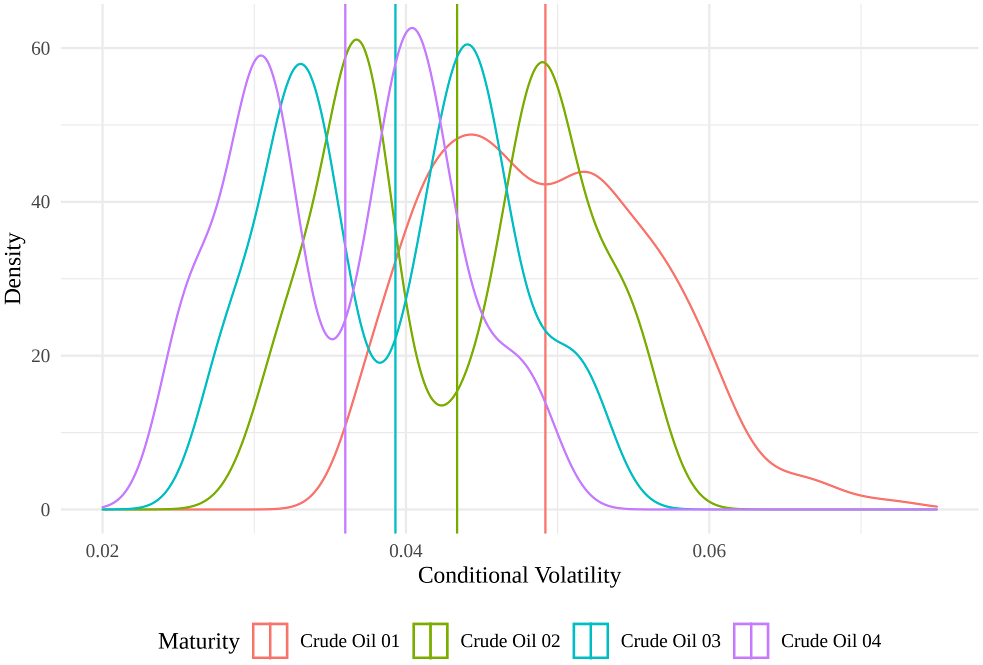
Note: The table reports estimated results from the regression: $h_{S\&P500} = \Upsilon_0 + \sum_{t=1}^{4} \Upsilon_1 h_{j,t} + \vartheta_{j,t}$ that examines how conditional volatility of crude oil impacts on the conditional volatility of equities during pre-financialisation and financialisation period. Standard errors $\vartheta_{i,t}$ in parentheses. Υ, h and CLF represents coefficient of crude oil futures conditional volatility, conditional volatility and crude oil futures contract respectively. ***,** and * denote statistical significance at 1%, 5%, and 10% level.

5.1.6. Samuelson Effect

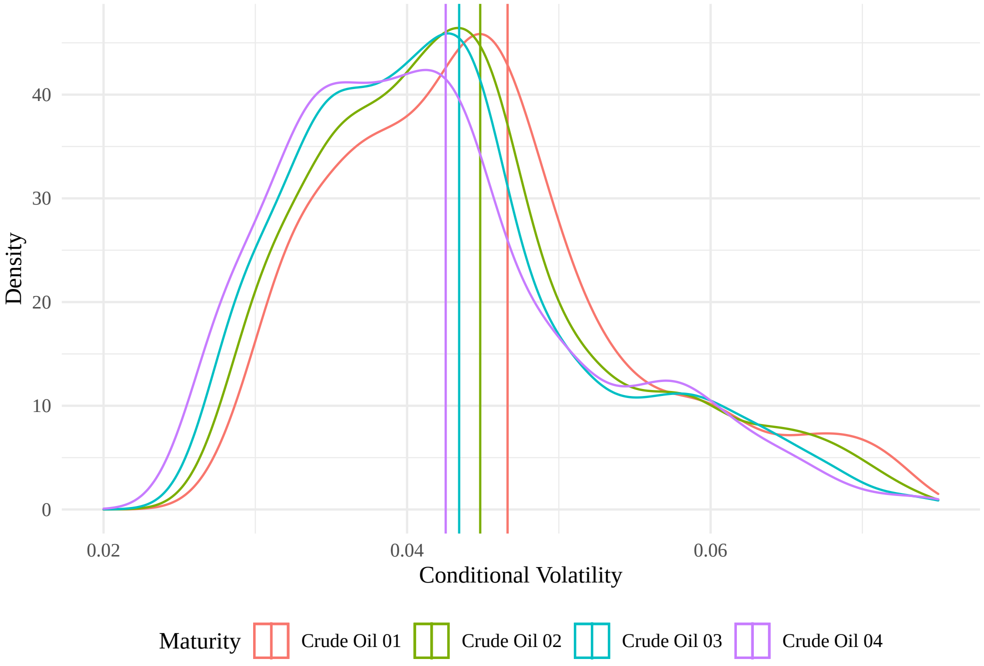
One of the most important features of commodity futures prices is the variation in nature of the price of nearby and deferred contracts. These variation in price behaviour results in decreasing volatility pattern i.e. long more volatile than short dated. Moreover, similar decreasing pattern is also noted for dependency between the prices of nearby and subsequent contracts, as the maturity of the contract increases. This phenomenon is often referred as Samuelson hypothesis (Samuelson 1965). Preliminary analysis on Section 4.3 suggest such appearance of the Samuelson hypothesis. These systematic patterns are broadly discussed in this section.

5.1.6.1. Samuelson Volatility Effect. There are several methods to perform Samuelson hypothesis test. Walls (1999) performs linear regression using high/low price to measure price volatility to be function of logarithm of time to maturity. We test whether there is a decreasing relation between volatility and the time-to-maturity of the contracts by using conditional volatility data gathered from our model and compare them (see Lautier and Raynaud 2011). The distribution of conditional volatility of crude oil-equity is shown in Figure 10. This figure illustrates how the conditional volatility changes over different maturity. In Figure 10a, before financialisation period, the distribution of conditional volatility shows two peaks in distribution which suggest volatility was concentration in two areas for all crude oil futures contracts. On the other hand, in Figure 10b during post financialisation period, the volatility seams to have one particular peak with wider range. Moreover, the distribution exhibits shifts to right after financialisation period. This implies an increase in conditional volatility. Furthermore, the mean of h_{CLF} during pre-financialisation period ranges between $0.0360 - 0.0492$ whereas mean of h_{CLF} of post financialisation period of $0.0425 - 0.0466$. Moreover, during the period of global crisis, maximum value of h_{CLF} is 0.1227.

We also observe that during pre-financialisation period, the mean of conditional volatility of nearby crude oil futures is higher than mean of most distant contract suggesting as maturity increases the conditional volatility of the contract decreases. The result supports *Samuelson maturity/volatility effect* for all four crude oil futures



(a) Pre-financialisation period



(b) Post-financialisation period

Figure 10: Distribution of conditional volatility for crude oil futures contracts

contract. We can say time-to-maturity explains a part of the volatility. Even though there is overall increase in conditional volatility since financialisation period, nearby crude oil futures mean is found to be lower after financialisation period. Overall, we find the maturity effect to be diminishing after financialisation period as most distant contract's conditional volatility is more increased (0.0065) than of next nearby contract's (0.0014) after financialisation of commodity market. The reason behind diminishing Samuelson hypothesis could be because market liquidity affecting more on volatility of nearby contract than distant contract which could decrease volatility of nearby contract more which is shown in Section 5.2.1.1.

The two-sample Kolmogorov–Smirnov (KS) test is used to test the null hypothesis that there is no difference between the distributions of time varying conditional volatility for crude oil futures contract during the pre-and-post financialisation period. D-statistics for the Kolmogorov–Smirnov test are reported in Table 8. The Kolmogorov–Smirnov test demonstrates that the distribution of conditional volatility from DCC for crude oil futures during pre-financialisation period significantly differs from that of the crude oil futures after financialisation period.

Table 8: Kolmogorov-Smirnov (KS) test on conditional volatility

	Crude Oil 01	Crude Oil 02	Crude Oil 03	Crude Oil 04
D statistic	0.2428	0.1543	0.1641	0.2505
p-value	0***	1.901e-07***	2.27e-08***	0***
Sample	distribution differs	distribution differs	distribution differs	distribution differs

Note:
This table presents Kolmogorov-Smirnov test on conditional volatility of crude oil futures during the pre-and-post financialisation period to investigate whether Samuelson hypothesis holds. The null hypothesis is rejected that state there is no difference between the two distrbution

[*] ***,** and * denote statistical significance at 1%, 5%, and 10% level.

In order to further look into Samuelson phenomenon, we utilise the non-parametric test developed by Jonckheere (1954) and Terpstra (1952) as Samuelson hypothesis testing requires testing of order of volatility among different contracts with different expiry date. Our test is different than Duong and Kalev (2008) and Jaeck and Lautier (2016) in a way that we use weekly conditional volatility extracted from VARX DCC GARCH model whereas the mentioned studies use natural logarithm of daily volatility. Moreover, our estimated volatility captures seasonality. We apply the Jonckheere–Terpstra (JT) test to investigate the null hypothesis whether the volatility of all crude oil futures contract series are equal, against the alternative hypothesis, which posits that higher volatility is observed in nearby crude oil futures contract series. The null and the ordered alternate form (where one must observe at least one strict inequality) of the JT test can be described as follows:

$$H_0 : \sigma_k = \sigma_{k-1} = ... = \sigma_1,$$

$$H_1 : \sigma_k \leqslant \sigma_{k-1} \leqslant ... \leqslant \sigma_1,$$

where k is the number of futures time series and σ_1 is the median of the conditional volatility of the time series, which is based on contracts nearest to maturity; σ_2 is the median of the conditional volatility of the time series, which is based on contracts second closest to maturity, and so on. The statistics from Jonckheree-Terpstra test are reported in Table 9. In both pre-and post-financialisation period, the null hypothesis is rejected which confirms there is higher volatility in nearby futures contracts than distant contracts. This evidence confirms that *Samuelson maturity effect* holds for crude oil futures contract in both sample period which implies that maturity effect is unaltered even after financialisation of commodity market. Moreover, the evidence suggests that Samuelson hypothesis is robust in crude oil futures market even after controlling seasonality. The result is consistent with findings of Jaeck and Lautier (2016) that Samuelson hypothesis holds for WTI crude oil markets. However, this outcome is contrary to that of Duong and Kalev (2008) who find Samuelson effect does not appear to hold in the NYMEX crude oil futures market.

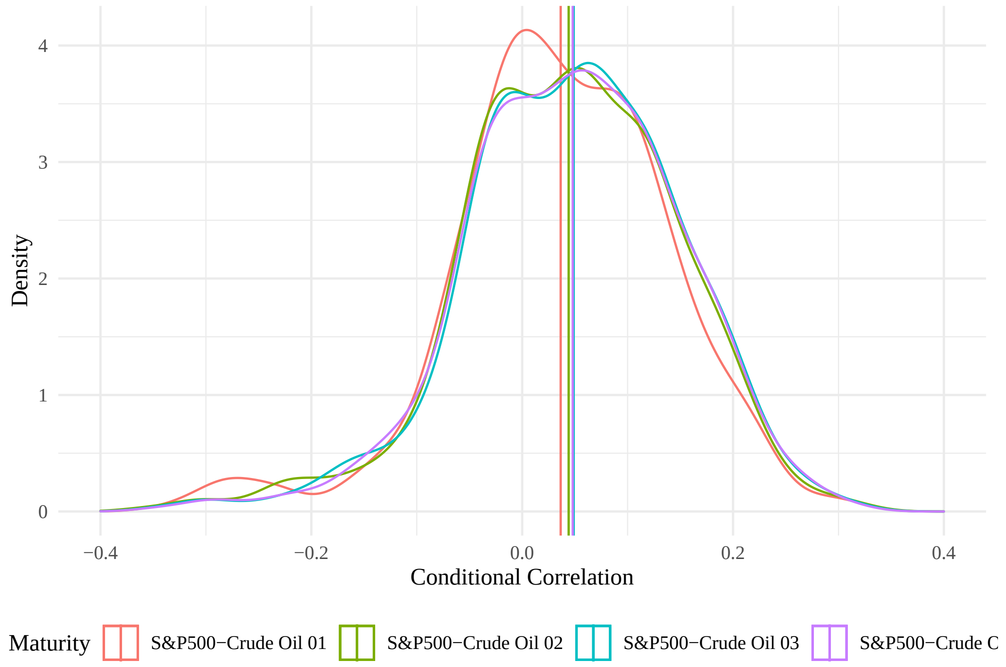
Table 9: Testing for the Samuelson effect using the Jonckheere–Terpstra test on conditional volatility

	Pre-financialisation Period	Post-financialisation Period
Z statistic	505738.0000	1830589.0000
p-value	0.0000	0.0000
h_1	0.0486	0.0443
h_2	0.0452	0.0428
h_3	0.0406	0.0415
h_4	0.0373	0.0406

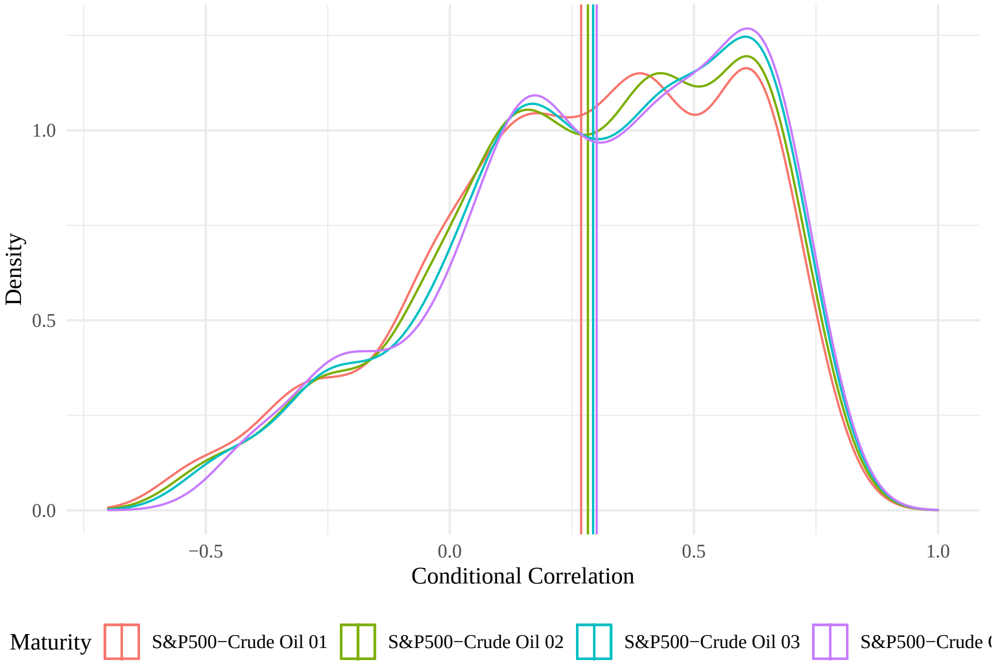
Note:
This table presents Jonckheere–Terpstra test on conditional volatility of crude oil futures during the pre-and post-financialisation period. h_1 (h_k) is the overall median for conditional volatility of crude oil futures on the closest contract to maturity (k-closest).

As the non-parametric tests are less powerful compared to the parametric tests, we also examine the Samuelson hypothesis by using linear regression with conditional volatility. Correlation coefficient of speculation index with conditional volatility from Table 12 shows that after financialisation, nearby crude oil futures coefficient (0.005) is higher than distant crude oil futures contract (0.002). However, results being insignificant we can not confirm that financialisation impacts more on nearby crude oil futures contract than distant contract through regression analysis.

5.1.6.2. Samuelson Correlation Effect. Turning now to the evidence on conditional correlation, Figure 11 compares the distribution of correlation of crude oil-equity for during pre-and post-financialisation period. Moreover, it depicts how the correlation changes over different maturity. Before financialisation period, shown in Figure 11a, the range of the distribution of correlation (−0.355 to 0.318) is lower than during post financialisation period (−0.568 to 0.792), shown in Figure 11b. The distribution exhibits shifts to the right when passing from pre-financialisation period to after financialisation period. This implies an increase in conditional correlation between commodity and equity market. The mean of pre-financialisation correlation is between 0.0365067 - 0.0488459 which is lower than



(a) Pre-financialisation period



(b) Post-financialisation period

Figure 11: Distribution of conditional correlation for crude oil

mean correlation of post financialisation period of 0.2690275 - 0.3008715 which also confirms increase in correlation after 2004. Overall, the distant contracts correlation with equity market have increased more than nearby contracts.

Furthermore, we observe during both pre-and post-financialisation period, mean of correlations between crude oil futures decreases as maturity of the contract increases. For instance, In Table C.2, mean of correlation between nearby and next nearby crude oil futures is 0.968 (pre) and 0.991 (post) whereas mean of correlation between nearby and most distant crude oil futures is 0.927 (pre) and 0.969 (post) that are lower (0.041-pre) and (0.022-post). This indicates that correlations become less dependant as the maturity increases and moves away from first underlying contract which shows the analogy of *Samuelson correlation effect*. These results are consistent with Schneider and Tavin (2018) on Samuelson correlation effect, who observes decreasing dependence pattern as the difference between futures contract's expiries increases.

What is surprising is that, we reject the effect of *Samuelson correlation effect* when we investigate correlation effect in crude oil-equities. Before financialisation period, the mean of correlation of nearby crude oil futures and S&P500 ($\rho_{S\&P500-CLF01}-$ 0.0365067) is lower than the mean of correlation of most distant crude oil futures and S&P500 ($\rho_{S\&P500-CLF04}-$ 0.0479383). This indicates the correlation of crude oil futures and S&P500 increases as maturity of crude oil futures increases. This also accords with our earlier observations noted on Table 5, which showed the increasing impact of volatility of S&P500 on correlation as maturity of the crude oil contract increases. Particularly, we find this relationship to be more prominent after financialisation period; that is, the mean of correlation of nearby crude oil futures and S&P500 ($\rho_{S\&P500-CLF01}-$ 0.2690275) is lower than the mean of correlation of most distant crude oil futures and S&P500 ($\rho_{S\&P500-CLF04}-$ 0.3008715).

In order to confirm the opposite Samuelson correlation effect, we perform JT test with null hypothesis that the correlation between S&P500 and crude oil futures contract series are equal, whereas alternative hypothesis is, higher correlation is observed with most deferred crude oil futures contract series. The null and alternative hypotheses are given below:

$$H_0 : \rho_k = \rho_{k-1} = ... = \rho_1,$$

$$H_1 : \rho_k \geqslant \rho_{k-1} \geqslant ... \geqslant \rho_1,$$

where k is the number of futures time series with longest maturity and ρ_1 is the median of the conditional correlation of the time series, which is based on contracts nearest to maturity; ρ_k is the median of the conditional correlation of the time series of kth maturity, which is based on contracts most distant contracts to maturity. Table 10 reports the statistics of JT test. Before financialisation period, the test confirms to be significant at 5% significance level whereas after financialisation period the test is significant at 1% significant which shows evidence of our prior observation on opposite to Samuelson correlation effect. In particular it shows that the opposite effect is more prominent after financialisation period. This result may partly be explained by the role of financialisation, as financial investors are investing in more longer horizon maturity contracts, thus the correlation between equity and crude oil futures with higher maturity are getting more integrated.

Table 10: Testing for the Samuelson effect using the Jonckheere–Terpstra test on conditional correlation

	Pre-financialisation Period	Post-financialisation Period
Z statistic	1018905.0000	2153986.0000
p-value	0.0277	0.0099
ρ_1	0.0365	0.3052
ρ_2	0.0491	0.3131
ρ_3	0.0531	0.3234
ρ_4	0.0500	0.3345

Note:
This table presents Jonckheere–Terpstra test on conditional correlation of crude oil futures during the pre-and post-financialisation period. ρ_1 (ρ_k) is the overall median for conditional correlation of S&P500 and crude oil futures on the closest contract to maturity (k-longest).

In regards to inspect overall change in distribution between the sample periods, we use the Kolmogorov–Smirnov test on conditional correlation; which is shown in the Table 11. As can be seen from the table, the distribution of conditional correlation between S&P500 and crude oil futures during pre-financialisation period varies from that of the crude oil futures after financialisation period.

Table 11: Testing for the Samuelson hypothesis using the Kolmogorov-Smirnov (KS) test on conditional correlation

	S&P500-Crude Oil 01	S&P500-Crude Oil 02	S&P500-Crude Oil 03	S&P500-Crude Oil 04
D statistic	0.565	0.5694	0.5728	0.5904
p-value	0***	0***	0***	0***
Sample	distribution differs	distribution differs	distribution differs	distribution differs

Note:
This table presents Kolmogorov-Smirnov test on conditional correlation between S&P500 and crude oil futures contract during the pre-and-post financialisation period.
* ***,** and * denote statistical significance at 1%, 5%, and 10% level.

Taken together, these results suggest that there is an association between volatility, correlation and maturity of the contracts. These linkage also varies depending upon the period of analysis. More precisely, it seems to be financialisation changes the nature of volatility in both crude oil futures and equity markets along with their correlations. We notice Samuelson maturity effect to hold for both sample periods; however; the effect is diminishing since financialisation. On the contrary, we find opposite effect to Samuelson correlation when we consider correlation between crude oil-equities; and this effect is more prominent since financialisation. As these results do not directly relate to financialisation variables, in the next section of the study, we explore our analysis by including measure of financialisation and liquidity factor. This will allow us to explore the impact of financialisation and liquidity on the volatility and the correlation.

5.2. Impact of Financialisation via Commodity-Specific Measuere

The first set of analyses examine the changing nature of volatility and correlation between crude oil futures and equity using sub-period analysis. This section explores the impact of financialisation and liquidity on the conditional volatility and the conditional correlations between crude oil futures and equity markets using speculative index measure and open interest. This analysis provides further understanding of the correlation and volatility dynamics, allowing us to examine whether commodities can be beneficial for diversification during financialisation period.

5.2.1. Regression Analysis

5.2.1.1. Link between Volatility, Speculative Activity and Open Interest. We consider a regression framework to investigate the relationship between conditional volatility, speculative activity and open interest during the pre- and post-financialisation period. The results of the regression analysis are set out in Table 12. The coefficient of speculation index (ζ_1) is negative and significant for nearby crude oil futures contract. This indicates that change in speculative activity contributes in explaining the change in volatility of nearby crude oil futures contract. The interpretation of this result is that increase in speculative activity lead to lower price volatility in nearby crude oil futures. However, after financialisation period, impact of financialisation on change in conditional volatility is found to be insignificant even though the correlation between change in speculative activity and change in volatility of crude oil futures is positive. This answers the question we posed. Manera, Nicolini, and Vignati (2013b) suggests that long term speculation have either negative or insignificant effects on volatility. It is an open question whether speculation can counteract the excess volatility during crisis period. We observe that the relationship between speculative activity and volatility of equity market and crude oil futures market has opposite direction during pre- and post-financialisation period which shows impact of speculation varies during the pre-and post-financialisation period. A plausible explanations for the changing nature of volatility dynamics during the pre-financialisation and post-financialisation windows for crude oil futures could be attributed to their relationship with the equity market over those two periods.

Table 12: Regression Results

	Dependent variable:									
	pre-financialisation period					financialisation period				
	$h_{S\&P500}$	h_{CLF01}	h_{CLF02}	h_{CLF03}	h_{CLF04}	$h_{S\&P500}$	h_{CLF01}	h_{CLF02}	h_{CLF03}	h_{CLF04}
$\zeta_1 SI$	0.005	-0.01^{**}	-0.002	-0.002	-0.002	-0.005	0.005	0.004	0.003	0.002
	(0.003)	(0.003)	(0.001)	(0.001)	(0.001)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
$\zeta_2 OI$	-0.01^{**}	-0.003	-0.001	-0.001	-0.001	-0.001	-0.01^{***}	-0.01^{***}	-0.01^{***}	-0.01^{***}
	(0.004)	(0.004)	(0.002)	(0.002)	(0.002)	(0.002)	(0.003)	(0.003)	(0.003)	(0.003)
ζ_0	-0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	-0.00	0.0000	0.0000
	(0.0001)	(0.0001)	(0.0000)	(0.0000)	(0.0000)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
Observations	572	572	572	572	572	833	833	833	833	833
R^2	0.01	0.01	0.01	0.01	0.01	0.001	0.01	0.01	0.01	0.01
Adjusted R^2	0.01	0.01	0.003	0.002	0.002	-0.001	0.01	0.01	0.01	0.01

Note: The table reports estimated results from the regression: $h_{ij,t} = \zeta_0 + \zeta_1 SI_i + \zeta_2 OI_i + e_{ij,t}$ examines the impact of speculative activity and open interests on conditional volatility of equities and commodities during pre-financialisation and financialisation period. Standard errors $e_{ij,t}$ in parentheses. h, ζ_0, ζ, CLF, SI, and OI represents conditional volatility, constant term, coefficient, crude oil futures,speculation index and open interest respectively. Speculation index is measured by $\frac{\textit{Non-commercial Long Position} - \textit{Non-commercial Short Position}}{\textit{Total Open Interest}}$ following Hedegaard2011. ***,** and * denote statistical significance at 1%, 5%, and 10% level.

If we now turn to impact of change in open interest (ζ_2) on the change in volatility of equity market, we find negative significant correlation between them and insignificant relationship with change in crude oil futures contract. On the other hand, after financialisation period change in open interest reduces volatility of crude oil futures contract whereas change in volatility of equity market is found to be insignificant. This indicates speculators provide additional liquidity in the market and stabilises the market price and hence leads to decrease in change in volatility of crude oil futures contract. This result is in line with Bessembinder and Seguin (1993), Watanabe (2001) and Floros and Salvador (2016) that increase in open interest reduces price volatility.

5.2.1.2. Link between Correlation and Speculative Activity and Open Interest. To explore the relationship between financialisation, liquidity and change in correlation between crude oil-equity market, we use regression analysis. Table 13 provides the result of regression analysis. We do not observe statistically significant correlation between speculative activity change and change in correlation of equity and crude oil futures market during both pre-and post-financialisation period. However, the direction of relationship differs between pre-financialisation and post-financialisation period. Similarly, we find insignificant results of change of interest impacting change in correlation of equity market and crude oil.

Table 13: Regression Model

	Dependent variable:							
	pre-financialisation period				financialisation period			
	ρ *S&P500-CLF01*	ρ *S&P500-CLF02*	ρ *S&P500-CLF03*	ρ *S&P500-CLF04*	ρ *S&P500-CLF01*	ρ *S&P500-CLF02*	ρ *S&P500-CLF03*	ρ *S&P500-CLF04*
$\eta_1 SI$	-0.02	-0.01	-0.01	-0.01	0.28	0.29	0.28	0.28
	(0.08)	(0.08)	(0.08)	(0.08)	(0.19)	(0.19)	(0.20)	(0.20)
$\eta_2 OI$	0.10	0.12	0.12	0.12	0.06	0.06	0.06	0.06
	(0.10)	(0.10)	(0.10)	(0.10)	(0.06)	(0.06)	(0.06)	(0.06)
η_0	-0.0004	-0.0004	-0.0004	-0.0004	0.001	0.001	0.001	0.001
	(0.002)	(0.002)	(0.002)	(0.002)	(0.003)	(0.003)	(0.003)	(0.003)
Observations	572	572	572	572	833	833	833	833
R^2	0.002	0.002	0.003	0.003	0.003	0.003	0.003	0.003
Adjusted R^2	-0.002	-0.001	-0.001	-0.001	0.001	0.001	0.001	0.001

Note: The table reports estimated results from the regression: $\rho_{ij,t} = \eta_0 + \eta_1 SI_i + \eta_2 OI_i + v_{ij,t}$ that examines the impact of speculative activity and open interests on conditional correlation between commodity futures and equity index during pre-financialisation and financialisation period. Standard errors $v_{ij,t}$ in parentheses. ρ, η_0, η, CLF, SI, and OI represents conditional correlation constant term, coefficient, crude oil futures, speculation index and open interest respectively. Speculation index is measured by $\frac{\textit{Non-commercial Long Position} - \textit{Non-commercial Short Position}}{\textit{Total Open Interest}}$. ***,** and * denote statistical significance at 1%, 5%, and 10% level.

So far we focus on regression analysis to investigate the effect of financialisation on crude oil futures and equity markets. Overall, result suggests there are some change in results between pre-and post-financialisation.

5.2.2. Granger-Causality Analysis

In the following sections, the standard Granger causality is applied to investigate potential causalities and impact of speculative activity and open interests on conditional volatility and conditional correlation. In accordance with the application of the VAR model, we investigate relationship between first differences of the variables and therefore include financialisation and liquidity variables with a time lag of one (week). Similar to James D. Hamilton (1994) and Sanders, Boris, and Manfredo (2004), we test the relationships in both directions.

5.2.2.1. Speculative Activity and Volatility. It is of interest to know whether speculative activity can be used in forecasting volatility of subsequent markets or investors' change their position based on past information of volatility. Hence, we examine whether speculative activity in the futures markets can influence the conditional volatility of equities and crude oil futures and vice-versa. The results are presented in the Table 14. The evidence indicates that there is unidirectional causality from speculative activity to conditional volatility of S&P500 and crude oil futures contract for full sample and financialisation period. This suggests that non-commercial traders do not follow trend rather drive volatility to fluctuate over the entire period and during financialisation period. During pre-financialisation period, there is no significant Granger causality link in either directions between conditional volatility and speculative activity. These findings reveal that financialisation measured by long term speculation lead the volatility of both equity or crude oil futures markets. Hence, we may say that speculative trading may drive volatility to change in the long run. This outcome is contrary to the findings of several studies for example Sanders, Boris, and Manfredo (2004) and Büyükşahin and Harris (2011) which has suggested that speculation does not precede price volatility. Moreover, Algieri and Leccadito (2019) finds insignificant effect of long run speculation Granger-causing crude oil futures conditional volatility. This does not appear to be the case in our findings. However, their result shows evidence of speculation Granger causes few other energy commodities. Our result may be explained by the fact that, we incorporate seasonality in conditional volatility and use speculation index that is highly correlated with speculative pressure, and therefore, increases the predictive power of speculation index on volatility. These results are consistent with James D. Hamilton (2009a) and Singleton (2014) who find speculation drives price fluctuation in oil markets. This observation support our hypothesis that financialisation or a measure of speculative activity may lead the volatility of crude oil futures prices.

5.2.2.2. Liquidity and volatility. Turning now to the analysis to know the impact of $(OI_{i,t})$ on the conditional volatility $(h_{ij,t})$ of the equity and the crude oil markets. The results from Granger-Causality test are presented in Table 15. The results indicate that Granger causality persists from open interest to conditional volatility of equity and nearby crude oil futures during pre financialisation. However, as the maturity of the crude oil futures contract increases, open interest loose causality link on the volatility of distant contracts. This suggests that nearby contracts

Table 14: Granger causality test between conditional volatility and speculation index

	Pre-financialisation		Post-financialisation	
Null Hypothesis	F Statistic	p-value	F Statistic	p-value
$SI \nRightarrow h_{S\&P500}$	0.566	0.4522	14.8465	1e-04***
$SI \nRightarrow h_{CLF01}$	0.9147	0.3393	10.4063	0.0013***
$SI \nRightarrow h_{CLF02}$	0.6848	0.4083	9.3076	0.0024***
$SI \nRightarrow h_{CLF03}$	0.6882	0.4071	9.6323	0.002***
$SI \nRightarrow h_{CLF04}$	0.6915	0.406	9.1208	0.0026***
$h_{S\&P500} \nRightarrow SI$	2.1463	0.1435	0.0468	0.8288
$h_{CLF01} \nRightarrow SI$	0.0059	0.939	0.4621	0.4968
$h_{CLF02} \nRightarrow SI$	0.0709	0.7901	0.4522	0.5015
$h_{CLF03} \nRightarrow SI$	0.0899	0.7644	0.4473	0.5038
$h_{CLF04} \nRightarrow SI$	0.1036	0.7477	0.6568	0.4179

Note:
The table reports the results of the Granger causality test between the first differences of conditional volatility and the first differences of speculation index during pre-financialisation period and financialisation period. h, CLF and SI represents conditional volatility, crude oil futures and speculation index respectively. Speculation index is measured by $\frac{\text{Non-commercial Long Position} - \text{Non-commercial Short Position}}{\text{Total Open Interest}}$.

[*] $\nRightarrow$ means "does not Granger-cause ". ***,** and * denote statistical significance at 1%, 5% and 10% level.

are more liquid than deferred contracts and thus open interest has more predictive power on nearby contracts than of deferred contracts. In additional, result shows that conditional volatility do not have forecasting power on open interest which is consistent with the findings of Fung and Patterson (1999). Investors tends to make decision based on liquidity rather than information from price fluctuation during pre-financialisation period.

Since financialisation, the Granger causality tests reports a different picture. There is bidirectional causality between change in conditional volatility of crude oil futures and change in open interest. This bidirectional causality can be explained by the fact that financialisation has increased open interest in the market. Particularly, the increase in non-commercial traders in the futures market, not only increases the trading for nearby contracts but also for deferred contracts. As open interest reflects trading activity, and thus may trigger the price volatility to change. Inversely, the change in volatility may impact on investors decision on speculative trading and may change the liquidity factor. It is worth mentioning that open interest leads conditional volatility of S&P500 before financialisation whereas after financialisation liquidity does not have predictive power on forecasting changing in volatility. The result contradicts Jena et al. (2018) that shows there is no causality from open interest to price volatility .

5.2.2.3. Speculative Activity and Correlation. To obtain information on how conditional correlation ($\rho_{ij,t}$) between the crude oil futures and the equity markets are linked to speculative activity, we carry out Granger-Causality test. The results are shown in Table 16. We barely find evidence of Granger causality from speculation index to conditional correlation. For instance, during financialisation period speculative activity may lead co-movement between equity and $2^{\text{nd}} - 4^{\text{th}}$ month crude oil contracts. However, the results is significant at 10% level of significance.

Table 15: Granger causality test between conditional volatility and open interest

	Pre-financialisation		Post-financialisation	
Null Hypothesis	F Statistic	p-value	F Statistic	p-value
$OI \nRightarrow h_{S\&P500}$	3.4311	0.0645*	0.2054	0.6505
$OI \nRightarrow h_{CLF01}$	3.0718	0.0802*	7.7701	0.0054***
$OI \nRightarrow h_{CLF02}$	3.4666	0.0631*	10.0459	0.0016***
$OI \nRightarrow h_{CLF03}$	2.2556	0.1337	10.3964	0.0013***
$OI \nRightarrow h_{CLF04}$	1.8333	0.1763	10.8829	0.001***
$h_{S\&P500} \nRightarrow OI$	0.0093	0.9231	8.3406	0.004***
$h_{CLF01} \nRightarrow OI$	0.2086	0.648	8.563	0.0035***
$h_{CLF02} \nRightarrow OI$	0.12	0.7292	9.345	0.0023***
$h_{CLF03} \nRightarrow OI$	0.1255	0.7233	10.0216	0.0016***
$h_{CLF04} \nRightarrow OI$	0.2522	0.6157	9.8	0.0018***

Note:

The table reports the results of the Granger causality test between the first difference of conditional volatility and the first difference of open interest during pre-financialisation period and post-financialisation period. h, CLF and OI represents conditional volatility, crude oil futures and open interest respectively.

* $\nRightarrow$ means "does not Granger-cause ". ***,** and * denote statistical significance at 1%, 5% and 10% level.

These results therefore need to be interpreted with caution. Hence, we cannot confirm that speculative activity does cause correlation to change after financialisation. There is a minor indication that financialisation may drive co-movement between these markets to change. Further analysis should be undertaken to confirm whether the co-movement is due to change in speculative activity.

Table 16: Granger causality test between conditional correlation and speculation index

	Pre-financialisation		Post-financialisation	
Null Hypothesis	F Statistic	p-value	F Statistic	p-value
$SI \nRightarrow \rho_{S\&P500\text{-}CLF01}$	1.4951	0.2219	2.6112	0.1065
$SI \nRightarrow \rho_{S\&P500\text{-}CLF02}$	1.9585	0.1622	3.0466	0.0813*
$SI \nRightarrow \rho_{S\&P500\text{-}CLF03}$	1.8603	0.1731	3.0486	0.0812*
$SI \nRightarrow \rho_{S\&P500\text{-}CLF04}$	1.7225	0.1899	3.0551	0.0809*
$\rho_{S\&P500\text{-}CLF01} \nRightarrow SI$	0.116	0.7335	1.7936	0.1809
$\rho_{S\&P500\text{-}CLF02} \nRightarrow SI$	0.0284	0.8662	2.0991	0.1478
$\rho_{S\&P500\text{-}CLF03} \nRightarrow SI$	1e-04	0.9902	2.4154	0.1205
$\rho_{S\&P500\text{-}CLF04} \nRightarrow SI$	0.0085	0.9267	2.2999	0.1298

Note:

The table reports the results of the Granger causality test between the first differences of conditional correlation and the first differences of speculation index during pre-financialisation period and post-financialisation period. ρ, CLF and OI represents conditional correlation, crude oil futures and speculation index respectively. Speculation index is measured by $\frac{\text{Non-commercial Long Position} - \text{Non-commercial Short Position}}{\text{Total Open Interest}}$.

* $\nRightarrow$ means "does not Granger-cause". ***,** and * denote statistical significance at 1%, 5% and 10% level.

5.2.2.4. Liquidity and Correlation. The Granger causality between conditional correlation and open interest less pronounced than between the volatility and open interest. The results are reported in Table 17. In pre financialisation period, there is no causality found between change in conditional correlation and change in open interest in any directions. However, we find that conditional correlation may lead open interest after the financialisation. In particular, we find the Granger causality between open interest and conditional correlation of equity and $2^{\text{nd}} - 4^{\text{th}}$ month contract to be significant. However, this relation is significant at 10% level and hence, there is a possibility that liquidity do not directly change the correlation between these markets.

Table 17: Granger causality test between conditional correlation and open interest

	Pre-financialisation		Post-financialisation	
Null Hypothesis	F Statistic	p-value	F Statistic	p-value
$OI \nRightarrow \rho_{S\&P500\text{-}CLF01}$	2.3314	0.1273	0.0058	0.9394
$OI \nRightarrow \rho_{S\&P500\text{-}CLF02}$	1.3038	0.254	6e-04	0.9798
$OI \nRightarrow \rho_{S\&P500\text{-}CLF03}$	1.3904	0.2388	6e-04	0.9806
$OI \nRightarrow \rho_{S\&P500\text{-}CLF04}$	1.439	0.2308	5e-04	0.9819
$\rho_{S\&P500\text{-}CLF01} \nRightarrow OI$	0.2095	0.6474	2.6652	0.1029
$\rho_{S\&P500\text{-}CLF02} \nRightarrow OI$	0.046	0.8303	3.4917	0.062*
$\rho_{S\&P500\text{-}CLF03} \nRightarrow OI$	0.0799	0.7775	3.6781	0.0555*
$\rho_{S\&P500\text{-}CLF04} \nRightarrow OI$	0.0754	0.7837	3.4037	0.0654*

Note:
The table reports the results of the Granger causality test between the first differences of conditional correlation and the first differences of open interest during pre-financialisation period and post-financialisation period. ρ, CLF and OI represents conditional correlation, crude oil futures and open interest respectively.

* $\nRightarrow$ means “does not Granger-cause”. ***,** and * denote statistical significance at 1%, 5% and 10% level.

The results in this study indicate that volatility linkage between crude oil futures and equity has changed considerably since the financialisation. This change in price volatility of these markets (see Section 5.2 can be explained by the financialisation process. In general, financial investors try to minimise their risk exposure by entering to commodity futures market increasing speculative activity. This increase in speculative activity increases the open interest in the market. The increase in open interest shows more information availability on prices and leads to higher liquidity in the commodity market. This leads to stability in prices and accordingly decreases price volatility in the markets. Moreover, we find some evidence that financialisation has altered the co-movement between equity market and crude oil futures market. In most of the cases as hypothesised we find distinct results for nearby contracts and deferred contracts (see Section 5.1.6). This could be due to the fact that front month contract's price reflects spot price. In Section 5.2.2, we find evidence that since financialisation open interest and volatility has bilateral causal relationship. As hypothesised, we find that seasonality effect not to be present in volatility since the financialisation. Moreover, Samuelson maturity effects holds in crude oil futures market. Interestingly, the effect starts to decrease after financialisation and the difference in volatility among crude oil futures contract starts to reduce. The most striking results to emerge from the analysis is that the opposite effect of Samuelson correlation between crude oil futures-equities and how the negative effect has become more noticeable since financialisation of commodities.

6. Robustness Check

We focus on three types of robustness checks: we assess whether the results are unaffected adopting alternative GARCH models, we check if using different measure of speculation changes the result and whether detrending a data series changes the result of impact of speculation.

As the accuracy of the conditional volatility and conditional correlation will effect on the exploration of financialisation impact; we repeat the previous analysis adopting AR(1)- DCC MGARCH models to see if the results are influenced by the type of models employed. The alternative volatility and correlation measure does not appear to affect our main findings and exhibit similar pattern to the previous findings. The results indicate that our conclusions are not estimation method sensitive.

We also consider two different measures of speculation to check robustness of regression analysis. First indicator is calculated by following Robles and Von Braun (2010).[22]. The second measure is calculated as the speculative pressure following De Roon, Nijman, and Veld (2000) and Sanders, Boris, and Manfredo (2004).[23] Interestingly, the hypotheses of speculative pressure does not Granger-cause conditional volatility is found to be significant for full sample period. The result suggests that depending on speculation measure whether short term or long term; may change the effect in volatility of crude oil futures. As long as we use long term speculation as speculation index, we find our results to be robust.

In addition, we use detrended open interest series to test our hypothesis know how it effects the conditional volatility and conditional correlation between equity and crude oil market. We find our results to be robust for both pre-and-post financialisation period. Overall, the results indicate that our conclusions are not estimation method, speculation measure or detrended open interest data sensitive.[24]

7. Conclusion

The paper analyses the possible connectedness between the equity and the crude oil futures markets. Instead of analysing the link of price return, we focus on the return volatility link of both markets to analyse impact of financialisation of commodity market. Based on preliminary analysis, we model the joint processes governing the returns of the S&P 500 stock index and the crude oil futures as VAR DCC GARCH with conditional volatility. Later, we use regression and Granger-causality analysis for conditional volatility, conditional correlation and how these variables are effected by financialisation or liquidity. Our empirical result shows some noteworthy findings. First, the correlation between crude oil futures and equity follows a time-varying dynamic process and tends to increase when the markets are more volatile. These results corroborate the findings of a great deal of the previous work in

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[22] Speculation Index = $\frac{\text{Non-commercial Long Position}}{\text{Total Open Interest}}$

[23] Speculative Pressure = $\frac{NCL-NCS}{NCL+NCS}$, where NCL represents non-commercial long position and NCS represent non-commercial short position.

[24] Robustness check results are available on request.

Forbes and Rigobon (2002), who suggest that cross-market interdependence are depended on market volatility and thus; their correlation incline to increase during high volatile period. This deteriorates the diversification benefits in the crude oil futures markets. Moreover, the inter-market dependence in their volatility suggests that either market can influence the other market to fluctuate. Hence, investors can use this information for trading strategy.

Second, looking into volatility dynamics, we find seasonal effect to weaken and to fade away for both return and volatility since the financialisation. Although the Samuelson volatility effect hold in both pre-financialisation (1993-2003) and post-financialisation (2004-2019) period, the effect is found to be diminishing for the post-financialisation period. Surprisingly, we find inverse effect of Samuelson correlation on the linkage between crude oil future-equity that suggests the correlation is higher between crude oil-equity with deferred contracts than with nearby contracts. This suggests that systematic patterns of volatility should not be overlooked while forecasting volatility/co-movement, in particular when the market is highly volatile or in crisis period. Moreover, the result implies that crude oil futures gradually started to act a financial asset since the financialisation.

Finally, overall the result suggests the existence of higher price volatility and co-movements among equities and crude oil futures since the financialisation. However, the commodity specific financialisation measure do not confirm such direct impact on either volatility or correlation. Rather, our findings are consistent with the view of increase in non-commercial investors in the market increases the open interest which provides liquidity and/or increases informational market efficiency and hence dampens the price volatility.

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Appendix

A.1. Appendix A

A.1.1. Summary of Theoretical Literature on Oil Price Risk and Models Indirectly Linked to Financialisation

John Maynard Keynes (1923), Hicks (1939), Hirshleifer (1988), Hirshleifer (1990) argue that futures market help in price discovery and managing price risk. In their hedging pressure theory, speculators in commodity markets fulfil the hedging needs of market participants/hedgers (who are trying to reduce risk to price change) by taking opposite positions (long or short). These speculators also add liquidity to the markets by increasing trading volume and hence, lower the price volatility which stabilises the market (Kaldor 1939; John M. Keynes 1930). Likewise, speculators are expected to improve the quality of price signals in commodity markets (Fama and French 1992; Fama 1970). However, Kaldor (1939) suggests that sometimes speculation may have a destabilising effect on financial markets. This is because speculators may get private information and may trade based on that information and may change the price (Grossman and Stiglitz 1980; Hellwig 1980). More precisely, an entrance of noise traders particularly positive feedback traders may distort prices from its' fundamental level (Grossman and Miller 1988). Financialisation being a recent event, these early theoretical models do not explicitly model financialisation; however, can address important issues for example information friction/asymmetries.

There is also recent theoretical literature developing model for oil price risk. For instance, Kogan, Livdan, and Yaron (2009) extended Litzenberger and Rabinowitz (1995) theory on oil market exhibits backwardation based on a production economy framework. Their model show that there is nonmonotone and convex (V-shape) relationship between the volatility of oil futures price and the basis (slope of forward curve). Gorton, Hayashi, and Rouwenhorst (2012) and Ekeland and Lautier (2017) accounted for both hedging pressure theory and storage theory while looking into oil futures risk. Acharya, Lochstoer, and Ramadorai (2013) investigate the interaction between futures risk premia and producers' hedging demand. Scorer, Baker, and Routledge (2017) and Ready (2018) demonstrate the importance for volatility of future price dynamics of oil. Kellogg (2014) introduced uncertainty in oil futures to investigate the impact on firm's investment strategy.

A.1.2. Methods Used to Capture Seasonal Effect

Geman and Nguyen (2005),Richter and Sørensen (2005) and Schneider and Tavin (2018) introduce models for spot price based on seasonal stochastic volatility. Using a similar method, Mirantes, Población, and Serna (2012) show that the stochastic model outperforms the deterministic model while looking into the seasonality of natural gas futures price. Todorova (2004) investigates seasonality in natural gas futures prices and shows that the Schwartz and Smith (2000) two-factor model fits better for seasonal price adjustment. Likewise, Lucey and Tully (2006) find that precious metal (both gold and silver) futures prices exhibit seasonality and prices are negatively affected on Mondays. Moreover, Suenaga, Smith, and Williams (2008) using a sinusoidal spline show that price volatility in natural gas shows strong seasonality and support Samuelson hypothesis. Schneider and Tavin (2018) show that depending on the difference in markets, different patterns of seasonality should be accounted for. Two mostly used approaches that capture seasonality are (1) dummy variable and (2) sinusoidal functions. Apart from these two methods, Weron (2014) indicates the use of the wavelets method for seasonality. Yu and Ryu (2020) use the filtering method of Hodrick and Prescott (1997) to decompose raw futures price data into four components: trend, seasonal, cyclical and irrational while assessing the impact of exchange-traded note (ETN) introduction on the underlying commodity futures market.

A.1.3. Methodological Discussion

In regards to our choice of econometric methods, we consider Generalised Autoregressive Conditional heteroscedasticity (GARCH) model as we want to analyse volatility and the extent of co-movement between the assets simultaneously.

Previous literature on dynamic dependencies between equity and commodity market uses time-varying copulas (used by Wen, Wei, and Huang (2012)), dynamic correlation analysis (used by Creti, Joëts, and Mignon (2013)), competing copula approaches (used by Delatte and Lopez (2013)), wavelet decomposition (used by Berger and Uddin (2016)), quantile regression (used by Reboredo and Uddin (2016)) and multivariate Markov switching (used by Chevallier (2012)). Later on, Diebold and Yilmaz (2014), Diebold and Yilmaz (2016) developed a volatility spillover framework that can capture volatility more effectively. This spillover framework has the ability to measure directionality in the transmission from one asset class to another asset class based on forecast error variance decompositions from vector autoregressions (VARs). However, this model does not consider volatility patterns while assessing spillovers or looks into time-varying correlation of these markets.

Unarguably, GARCH family of the models has been the standard approach to model volatility of financial time series. Our econometric framework is based on DCC-GARCH model of Engle (2002). This model has been used to specify time-varying variance and co-movements between equity markets and other financial/fundamental variables (see e.g. Antonakakis, Chatziantoniou, and Filis 2013), between equity and crude oil/other commodities (among others, Basher and Sadorsky 2016; Büyükşahin and Robe 2011; Sadorsky 2014), and between commodities (see e.g. Ma et al. 2020).

A.1.4. Likelihood Ratio (LR) Test

To acess whether to include seasonal dummy or not following Likelihood ratio (LR) test is performed.

$$[-2(\log \text{likelihood}_{\text{no seasonal dummy}} - \log \text{likelihood}_{\text{seasonal dummy}})]$$

The test follows a χ^2 distribution with 3 degrees of freedom. Table C.1 in Appendix C.3 shows that all crude oil futures contracts are significant at 95% level of confidence. This implies that the joint effects of all seasonal dummies are significantly different from zero confirms that there is a presence of seasonal effects in crude oil futures market.

This is due to the fact that the demand for energy commodity fluctuate extensively depending on season and thus seasonal pattern is observed in their price series (Pardo, Meneu, and Valor 2002; Hunt, Judge, and Ninomiya 2003). Moreover, our result is congruent with Wu, Guan, and Myers (2011) where quarterly seasonality exists in crude oil futures price. On the other hand, equity index are found to be insignificant for including seasonal dummy. However, as in this study we focus on co-movement between equity and crude oil futures market, we consider to include the dummies to know whether capturing seasonal effect changes volatility link or correlation between the equity and crude oil futures market.

A.1.5. Estimation Method

The DCC model is estimated using the Quasi-Maximum Likelihood estimator (QMLE) under a multivariate Student t-distribution (see Harvey, Ruiz, and Sentana 1992; Fiorentini, Sentana, and Calzolari 2003).[25]. Use of QMLE method is robust to any variation from normality conditions (Ling and McAleer 2003). Jondeau and Rockinger (2006) use both the full maximum likelihood method and the two-step method and finds that both methods provide very similar results. Moreover, Jensen and Lunde (2001) and Venter and Jongh (2001) postulate that a change in the distribution of errors in the second step does not affect the estimation of the parameters as the normality assumption of the innovations is rejected for each volatility series. We assume the standardized errors,υ , are multivariate Student's t-distributed with ν degrees of freedom and the joint density of $\upsilon_1, ..., \upsilon_T$

$$f(\upsilon_t|\nu) = \prod_{t=1}^{T} \frac{\Gamma(\frac{\nu+n}{2})}{\Gamma(\frac{\nu}{2})[\pi(\nu-2)]^{\frac{n}{2}}} \left[1 + \frac{\upsilon_t^T \upsilon_t}{\nu - 2}\right]^{-\frac{n+\nu}{2}} \tag{24}$$

where, $\Gamma(.)$ is the gamma function.

Assuming Gaussian distributed errors, the first stage quasi-likelihood is as follows

$$\begin{aligned} \ln(L_1(\phi)) &= -0.5 \sum_{t=1}^{T} [n \ln(2\pi) + 2 \ln(\mid D_t \mid) + \ln(\mid I_n \mid) + \varepsilon_t^{'} D_t^{-1} I_n D_t^{-1} \varepsilon_t] \qquad (25) \\ &= -0.5 \sum_{t=1}^{T} [n \ln(2\pi) + 2 \ln(\mid D_t \mid) + \varepsilon_t^{'} D_t^{-1} I_n D_t^{-1} \varepsilon_t] \\ &= -0.5 \sum_{t=1}^{T} n \ln(2\pi) + \sum_{i=1}^{n} \left[\ln(h_{it}) + \frac{\varepsilon_{it}^2}{h_{it}}\right] \\ &= \sum_{i=1}^{n} (-0.5 \sum_{t=1}^{T} \left[\ln(h_{it}) + \frac{\varepsilon_{it}^2}{h_{it}}\right] + \text{constant}) \end{aligned}$$

where, parameter set $\phi_i, i = 1, ..., n$ are estimated assuming univariate GARCH models with Gaussian distributed errors. The remaining parameter $\psi = (\theta_1, \theta_2, \nu)$ are estimated in the second step using log-likelihood by using the

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[25] Under certain conditions the method of pseudo-maximum likelihood returns consistent and asymptotically normal estimators (Sheppard 2001)

estimated parameter from step one. The second stage of quasi-maximum likelihood function is as follows

$$\begin{aligned}\ln(L_2(\psi)) = \sum_{t=1}^{T}(\ln\left[\Gamma(\frac{\nu+n}{2})\right] - \ln\left[\Gamma(\frac{\nu}{2})\right] - \frac{n}{2}\ln\left[\pi(\nu-2)\right] \\ -0.5\ln\left[\mid D_t R_t D_t \mid\right] - \frac{\nu+n}{2}\ln\left[1+\frac{\varepsilon_t^{'} D_t^{-1} R_t^{-1} D_t^{-1}\varepsilon_t}{\nu-2}\right]) \\ = \sum_{t=1}^{T}(ln[\Gamma(\frac{\nu+n}{2})] - \ln[\Gamma(\frac{\nu}{2})] - \frac{n}{2}\ln[\pi(\nu-2)] \\ -0.5\ln[\mid R_t \mid] - \ln[\mid D_t \mid] - \frac{\nu+n}{2}\ln[1+\frac{\epsilon_t^{'} R_t^{-1}\epsilon_t}{\nu-2}])\end{aligned} \tag{26}$$

Various Figures

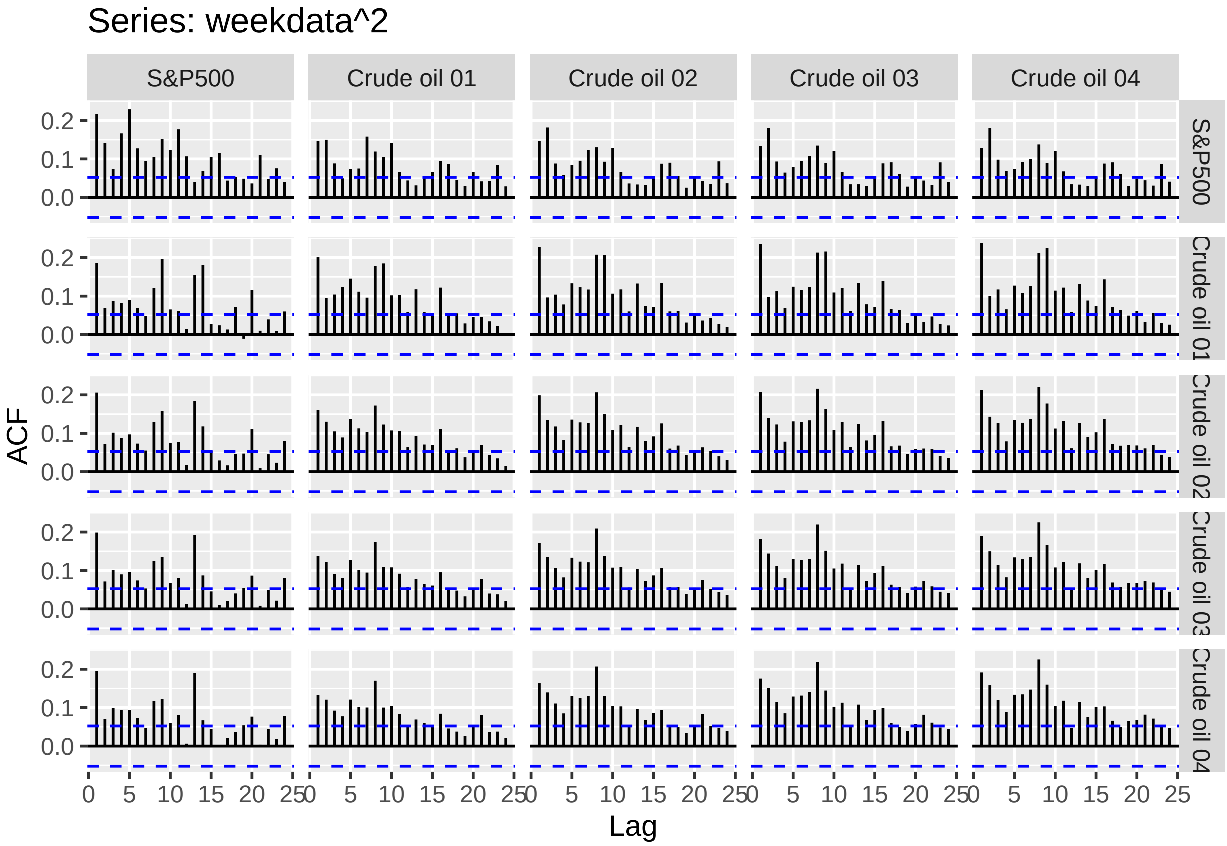
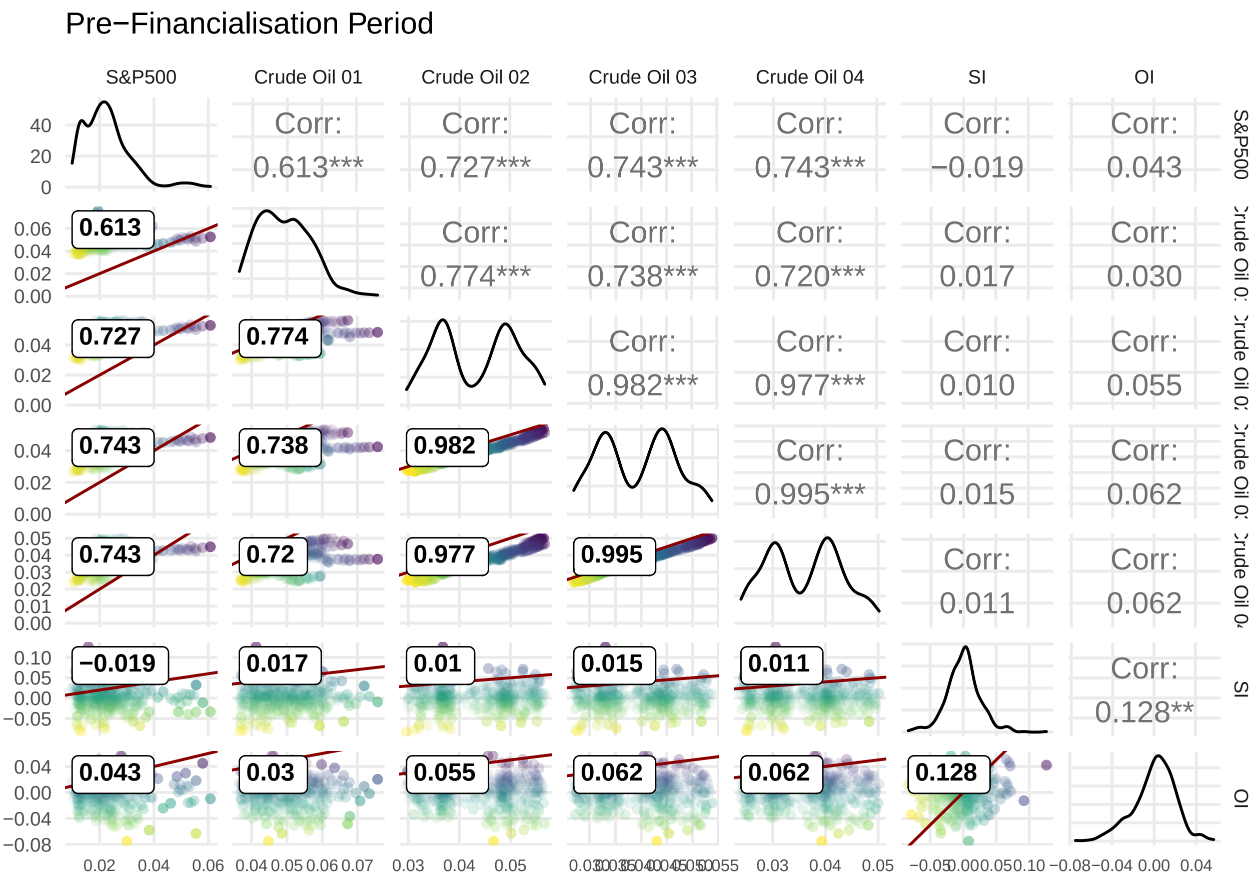


Figure B.1: ACF of S&P500 and crude oil futures squared return series

Figure B.2: PACF of S&P500 and crude oil futures squared return series



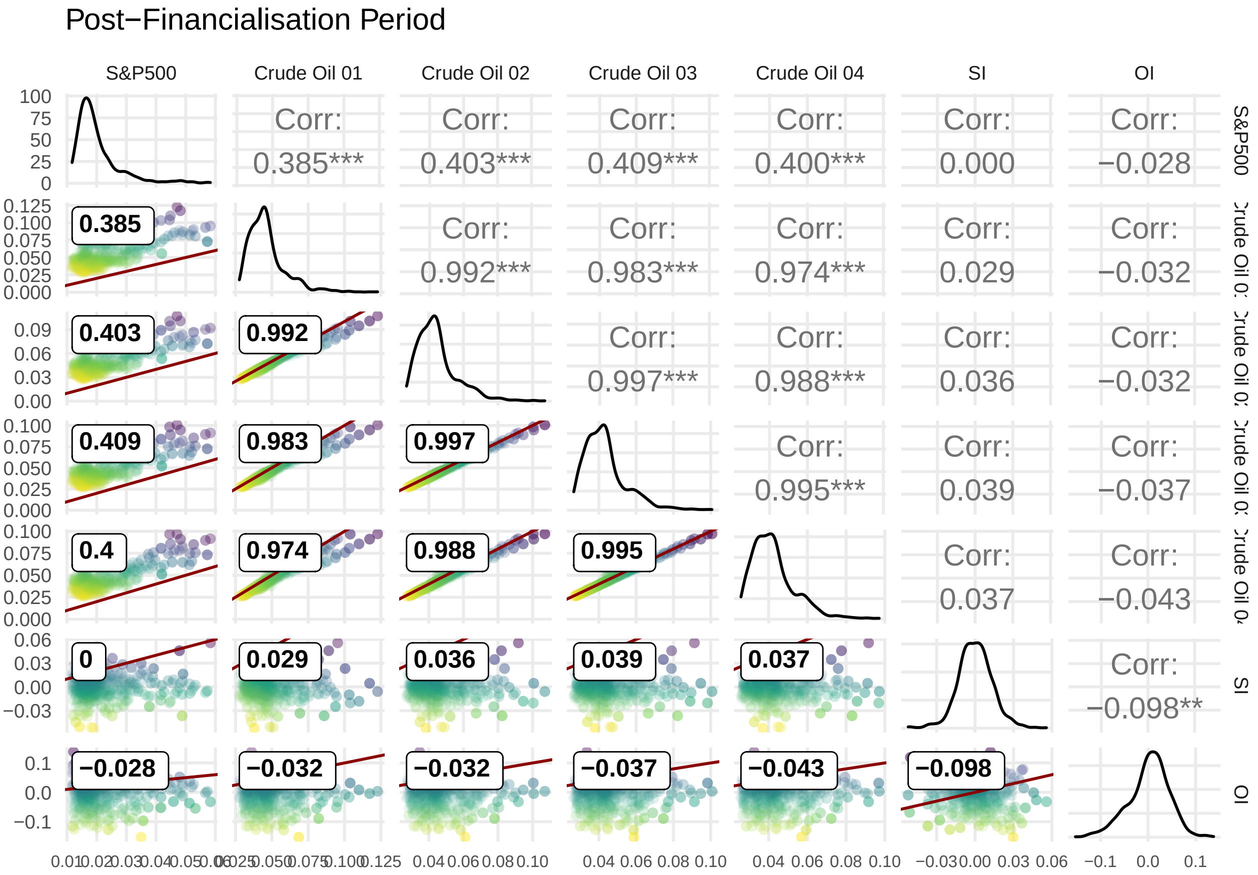
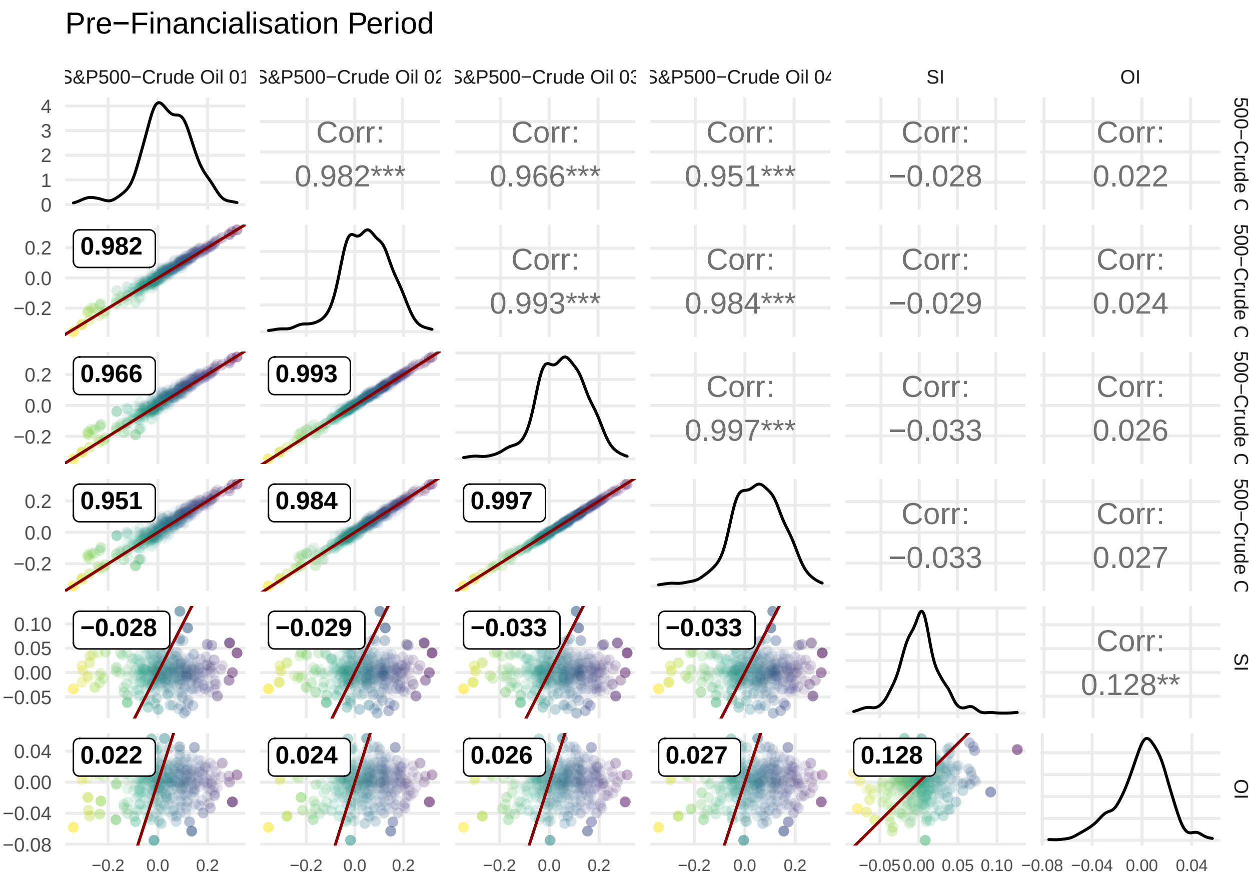
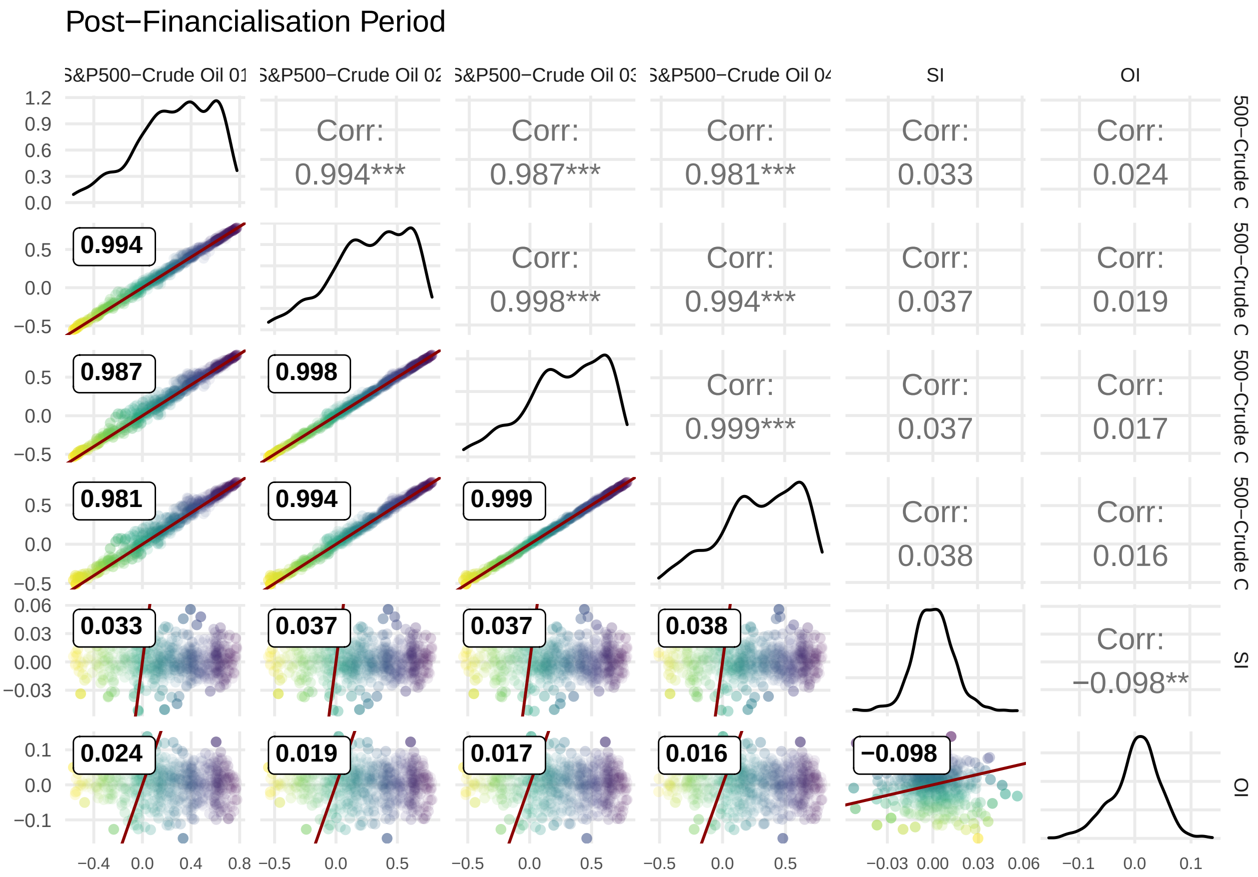


Figure B.3: Correlation between conditional volatility, speculation index and open interest



Pre−Financialisation Period



Post−Financialisation Period

Figure B.4: Correlation between conditional correlation, speculation index and open interest

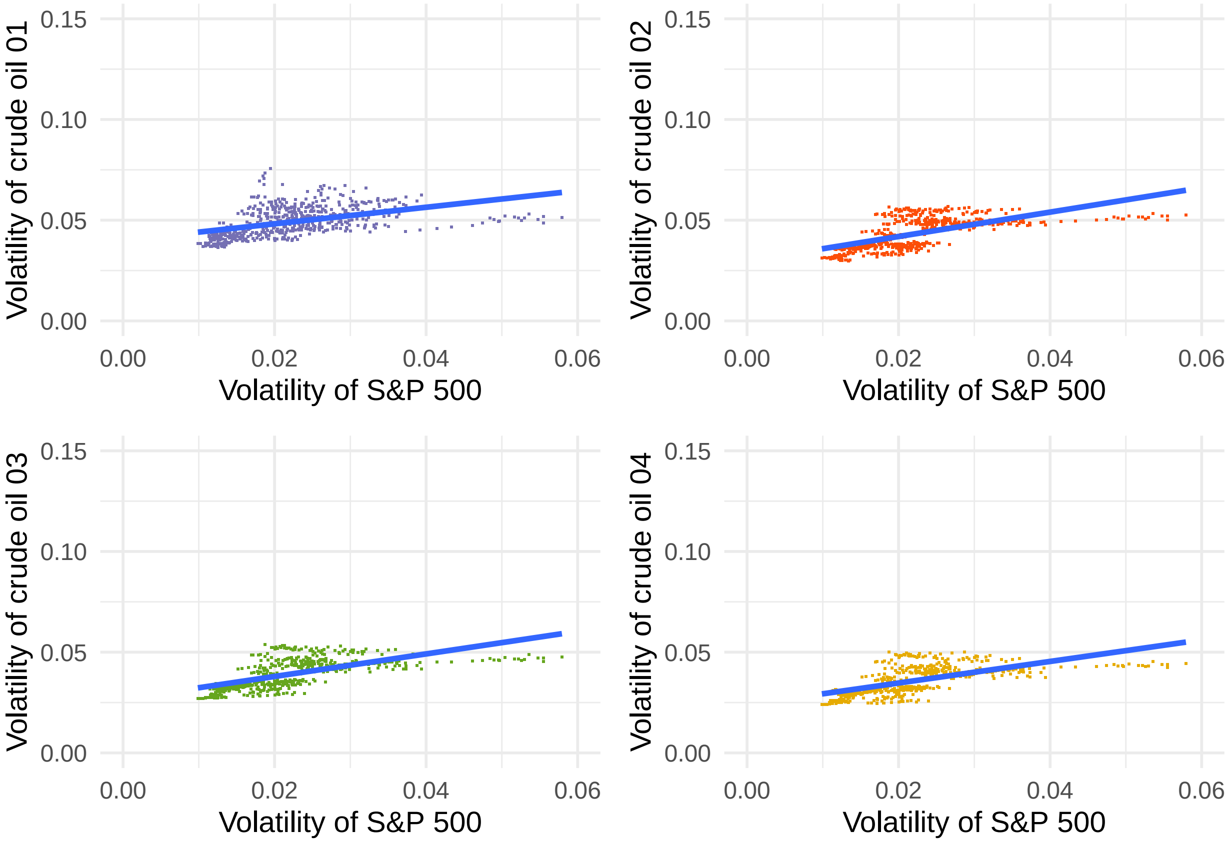


Figure B.5: S&P 500 Index's conditional volatility vs crude oil futures contracts conditional volatility before financialisation

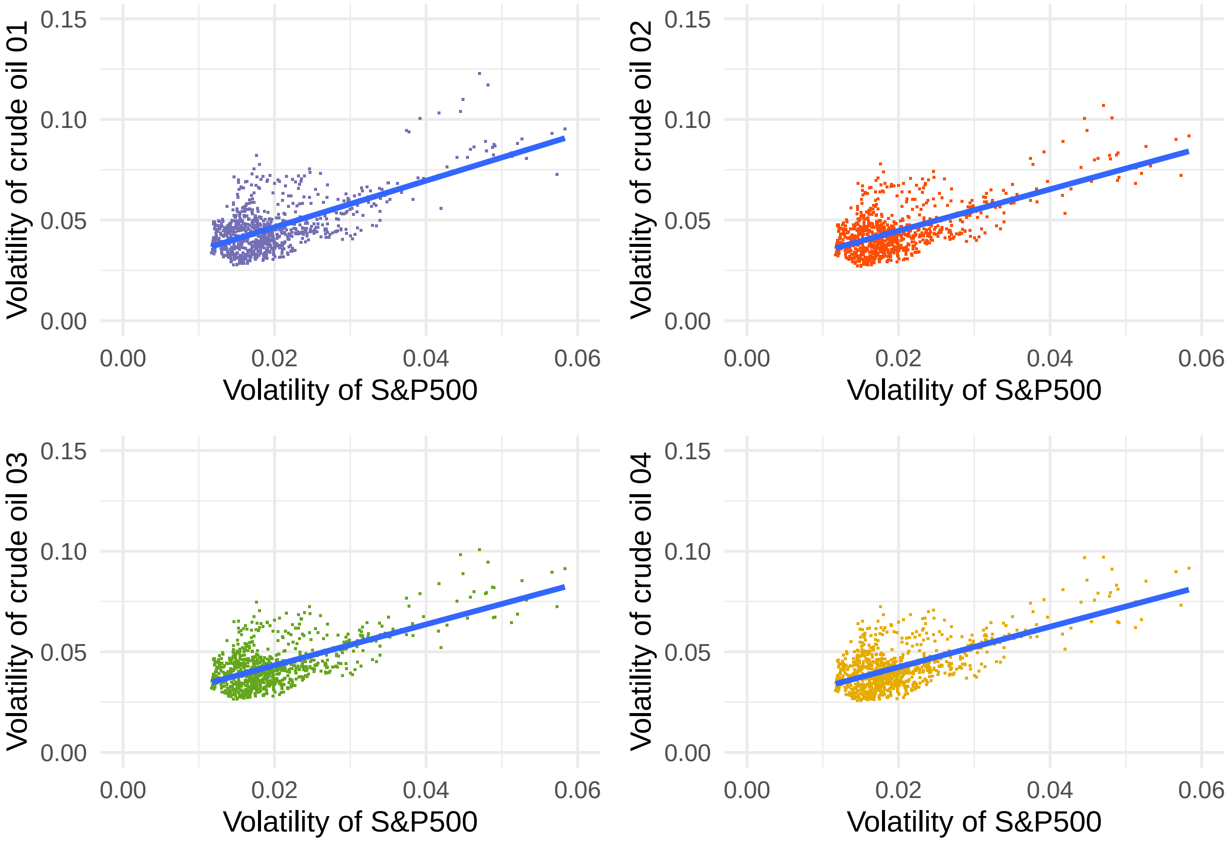


Figure B.6: S&P500 Index's conditional volatility vs crude oil futures contracts' conditional volatility after financialisation

C.3. Appendix C

C.3.1. Various Tables

Table : Model Selection

Distribution	***Akaike Information Criteria***	***Bayesian Information Criteria***
	With VAR component	
Normal	-32.63807	-32.31349
Student	-34.56479	-34.23648
Laplace	-34.34083	-34.01625
	Without VAR component	
Normal	-32.69207	-32.53538
Student	-35.10462	-34.94420
Laplace	-34.82129	-34.66460

Note:

This table shows Akaike information criteria and Bayesian information criteria for selecting VARX-DCC-GARCH.

Table C.1: Likelihood Ratio Test

	S&P500	Crude oil 01	Crude oil 02	Crude oil 03	Crude oil 04
LR statistic	3356.55	2243.97	2357.34	2433.7	2493.8
p-value	0.5879	0.0471**	0.0423**	0.0408**	0.0404**

Note:
This table presents the likelihood estimation for capturing seasonality for the return series of equity and crude oil futures contracts. LR is the test statistic of the likelihood ratio test. The test follows a χ^2 distribution with 3 degrees of freedom that is 3 seasonal dummies for winter, summer and fall seasons.

* ***,** and * denote statistical significance at 1%, 5%, and 10% level.

Table C.2: Mean test for dynamic conditional correlation

	Obs. Pre-Financialisation	Obs. Post-Financialization	Mean Pre-Financialisation	Mean Post-Financialisation	t-stat
S&P500-Crude Oil 01	573	833	0.037	0.269	-19.933***
S&P500-Crude Oil 02	573	833	0.044	0.283	-20.660***
S&P500-Crude Oil 03	573	833	0.049	0.294	-21.190***
S&P500-Crude Oil 04	573	833	0.048	0.301	-22.080***
Crude Oil 01 - 02	573	833	0.968	0.991	-41.127***
Crude Oil 01 - 03	573	833	0.947	0.981	-34.452***
Crude Oil 01 - 04	573	833	0.927	0.969	-26.931***
Crude Oil 02 - 03	573	833	0.993	0.997	-22.646***
Crude Oil 02 - 04	573	833	0.982	0.989	-9.342***
Crude Oil 03 - 04	573	833	0.996	0.996	1.356

Note:

This table presents mean test for dynamic conditional correlation extracted from VARX DCC GARCH process for pre-financialisation period and post financialisation period.

* ***,** and * denote statistical significance at 1%, 5%, and 10% level.