The Dynamic Interplay of Crude Oil Futures and Equity Markets Across Pre- and Post-Financialisation Eras

Sania Wadud[*], *Robert B. Durand*[**], *and Marc Gronwald*[***]

ABSTRACT

We examine the effect of financialisation of futures markets has on the relationship between crude oil futures and equities. We particularly account for the systematic patterns of commodity price volatility, such as seasonality and maturity effects, across two distinct periods: the pre-financialisation era (1993-2003) and the post-financialisation era (2004-2019). Non-commercial speculation has a negative impact on crude oil futures' volatility before financialisation (1993-2003) and liquidity emerged as a negative determinant of volatility in post-financialisation (2004-2019). Seasonality is weaker since financialisation. The Samuelson effect, characterised by an increase in the volatility of contracts as expiration approaches, weakens in the post-financialisation period.

Keywords: financialisation, volatility dynamics, Samuelson hypothesis, correlation, seasonality.
JEL: Q14, G12, G15 ,G10, C52

1. INTRODUCTION

The growing interconnectedness between financial and commodity markets has generated considerable interest among researchers, especially in the context of financialisation. Financialisation, broadly defined as the increasing dominance of financial motives, markets, actors, and institutions, has altered the nature and behaviour of commodity markets over the last few decades. Scholars such as Cheng and Xiong (2014) and Basak and Pavlova (2016) have argued that the influx of speculative capital, particularly through derivative instruments, has transformed commodities like crude oil into financial assets rather than mere consumption goods. This shift has intensified the volatility and correlation between commodity and equity markets, suggesting that commodity prices increasingly reflect financial market dynamics rather than traditional supply and demand fundamentals. Consequently, understanding the interconnectedness and volatility spillovers between these markets has become critical, especially considering the role of speculative trading in amplifying market movements, as argued by Tang and Xiong (2012) and Fattouh et al. (2013).

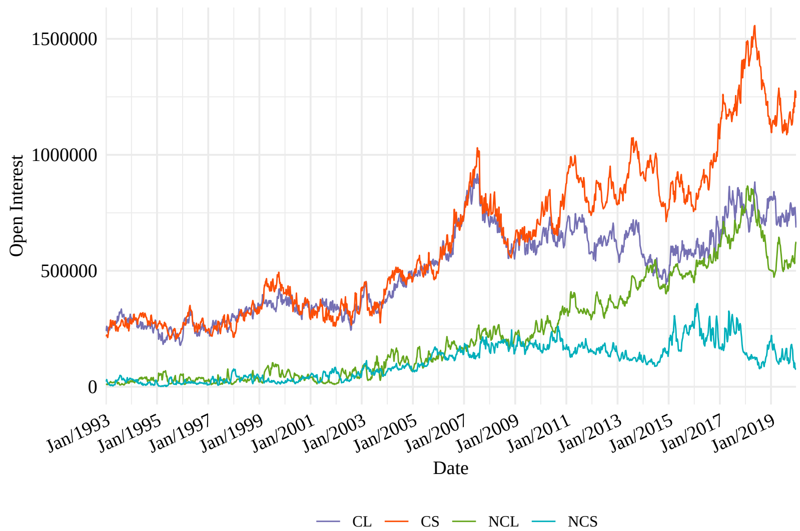
This paper contributes to this discourse by investigating the dynamic relationship between the equity and the crude oil futures markets from 1993 to 2019, focusing specifically on the connectedness of return volatility, rather than price returns, between these two markets. This approach allows us to assess the impact of the financialisation of commodity markets, which here refers to the marked increase in positions (both long and short) held by non-commercial traders—typically speculative market participants—in the crude oil futures market, especially from 2004 onwards.[1] Weiner (2002) notes that speculators may manipulate the market or, if inadequately informed, trade based on past trends or herd behaviour instead of focusing on market fundamentals.

Since the enactment in the United States of the Commodity Futures Modernisation Act (CFMA) of 2000, many commodity markets have experienced a significant surge in trading volumes, alongside a rise in the number of positions held by non-commercial investors (Frenk, 2010; CFTC, 2010). The legislative change supported the growth

[*]Corresponding author. Leeds University Business School, University of Leeds, Leeds, UK. E-mail: s.wadud@leeds.ac.uk.
[**]Finance Discipline, Curtin University, Australia.
[***]International Business School Suzhou, Xi'an Jiaotong-Liverpool University, Suzhou, China, CESifo, ifo Institute, and Aberdeen Centre for Research in Energy Economics and Finance

[1]This growth is discussed in Frenk (2010) and CFTC (2010). In futures markets, non-commercial traders, or speculators, seek to profit from market price movements rather than hedging against them, unlike commercial traders who use futures primarily to manage price risks. However, it should be noted that commercial traders occasionally engage in speculative activity.

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



of 'financial entrepreneurship' by exempting hedge fund activity and energy derivative trading from regulation. The Act may also have 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). Additionally, the CFMA introduced mechanisms like the Enron, London, and swap loopholes, which relaxed speculative position limits (Frenk, 2010). As a consequence, 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 et al., 2011). Moreover, there has been an increase in co-movement across commodities and between equities (Wadud et al., 2023) and commodities (Ma et al., 2021). The open interest data displayed in Figure 1 the substantial growth in positions held by both commercial and non-commercial traders in crude oil futures, reflecting this period of intensified financialisation.

In general, theory suggests that an increase in trading volume contributes to the price discovery process. However, the unprecedented surge in commodity futures trading volumes raises a question, much debated in the empirical literature, about the possible cause of observed changes in price, volatility, and degree of co-movement between commodities and equities. Do these observed shifts in commodity price behaviour reflect underlying economic fundamentals and business cycle dynamics, as argued by (Fattouh et al., 2013; Hamilton, 2009b; Kilian and Murphy, 2014). Or are they driven by financial innovations such as the expansion of derivative instruments, which might create new dynamics in the market beyond traditional supply and demand, as suggested by (Masters, 2008; Tang and Xiong, 2012).

Moreover, crude oil pricing dynamics is complex and can be affected by factors like: (i) demand and supply; (ii) inventories; (iii) speculation; (iv) uncertainty; (v) seasonality; and (vii) political factors and technological developments.

Our study addresses these questions by exploring the impact of financialisation and presents evidence on whether financialisation has altered underlying volatility dynamics of the crude oil futures market, specifically the connectedness between equities and crude oil futures through return volatility linkage. Unlike previous studies, our analysis considers unique volatility patterns in commodity prices— such as clustering effect, seasonality, Samuelson volatility, and correlation effect- in order to capture the potential influence of financialisation more comprehensively.[2]

One of the rationales for examining volatility dynamics is that if the Samuelson hypothesis holds, estimates of volatility must take into account the period remaining before the underlying contract matures if the valuation of a

[2]The Samuelson hypothesis, proposed by Samuelson (1965), suggests that the volatility of futures price increases as the contract expiration time draws closer.

derivatives instrument is to be accurate (Bessembinder and Seguin, 1993). This theory has practical relevance because by observing intra- and inter-seasonal price movement, producers can determine next season's optimal production level, and investors can make the appropriate investment decision; this therefore minimises seasonal price variability (United Nations, 2009, pp. 24).[3] Failure to account for these systematic volatility patterns may lead to an overestimation of the volatility (price and return) and cross-market linkage (between return and volatility) between commodity futures and equity, which will thus cause the role of financialisation to be overestimated.

Our study narrows its focus to crude oil futures, given their prominence as the most actively traded energy commodity. Crude oil, as a primary energy source, has a unique influence on the pricing of other assets, and its market behaviour offers a lens through which to understand broader financialisation trends. By examining time-varying return volatility and dynamic conditional correlations between crude oil and equity markets- particularly the S&P 500 Index; this study provides new insights into the financialisation of crude oil futures. Employing a VAR-DCC-GARCH model, we account for seasonality as an exogenous variable, distinguishing this analysis from previous research that has typically overlooked such factors. Through (i) sub-sample analysis and (ii) commodity-specific measures, we explore financialisation's impact across two distinct periods: the pre-financialisation era (1993–2003) and the post-financialisation era (2004–2019). 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, using regression and Granger causality analysis.[4]

Our findings present several noteworthy conclusions. First, we observe that speculative activity, measured by changes in net commercial long positions, dampened crude oil futures volatility prior to financialisation. In the post-financialisation era, increased open interest (indicating higher liquidity) appears to mitigate volatility further.

Second, our examination of seasonal volatility reveals that seasonality has weakened since financialisation, with crude oil futures behaving increasingly like financial assets influenced by the broader equity market.

Third, our analysis indicates that financialisation has diminished the maturity effect in crude oil futures. Our study rejects the Samuelson correlation effect in crude oil-equity, noting that the correlation between crude oil futures and equities increases as the contract moves away from the underlying. This effect has become more prominent since financialisation, implying a shift in their market behaviour.

Overall, we find some evidence that is consistent with the effect of financialisation in crude oil futures and equity markets. However, there is no pervasive evidence that financialisation has directly changed either volatility patterns or the volatility link between crude oil futures and equity markets. We note that there could be other drivers altered by the financialisation, such as a change in inventory (Gorton et al., 2013), change in demand level (Pradhananga, 2016), interest rate (Qin et al., 2024), etc., that might indirectly change the patterns of volatility and the volatility link between these markets.

The remainder of this paper is organised 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 describes the data employed for empirical analysis followed by section 4 which explains the measures and methodology employed for the impact of financialisation on volatility and correlation. 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 summarising the key results.

[3] Inter-seasonal price volatility provides information on the change in price in the long-run whereas intra-seasonal volatility shows the information on the change in price within the growing season (Goodwin and Schnepf, 2000).

[4] Recently, Ding et al. (2021) used a DCC-GARCH framework to analyse the impact of financialisation on the co-movement between some commodities and equity. Our study 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 focuses solely on volatility.

2. LITERATURE REVIEW

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

2.1 Theoretical Models related to financialisation, Commodity and Equity Markets

The theoretical literature on commodity financialisation has primarily focused on understanding the behaviour of financial investors in commodity markets and the resultant price impacts, sparking an ongoing debate regarding the influence of non-commercial participants on price volatility. For instance, Ekeland et al. (2019) and Goldstein and Yang (2022) examine how increased financial participation influences commodity pricing dynamics, particularly with regard to non-commercial participants' roles in exacerbating price swings.

Further contributions emphasise the crucial role of inventory levels in shaping commodity price dynamics and speculation effects, especially for storable commodities. Inventory level, as epitomised by studies such as Gilbert et al. (1992), Routledge et al. (2000) and Vercammen and Doroudian (2014), are critical to understanding price behaviours in commodity markets where storage constraints and costs inherently link futures and spot prices.[5] Equity price dynamics, on the other hand, do not rely on inventory levels. The differences between the 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, the storage of a physical commodity will incur costs. The physical commodity can be stored for future consumption at a storage cost, but one cannot borrow a physical commodity from the future for current consumption. Seasonality in demand or supply creates seasonal variation in prices, and storage costs mean that this seasonal price variation cannot be perfectly smoothed out. Consequently, the commodity futures prices are quoted based on delivery dates and may include idiosyncratic elements, such as perishability, delivery location, storage and shipping costs and seasonal effects, which adds a complexity to commodity futures that equities do not experience (Juvenal and Petrella, 2015).

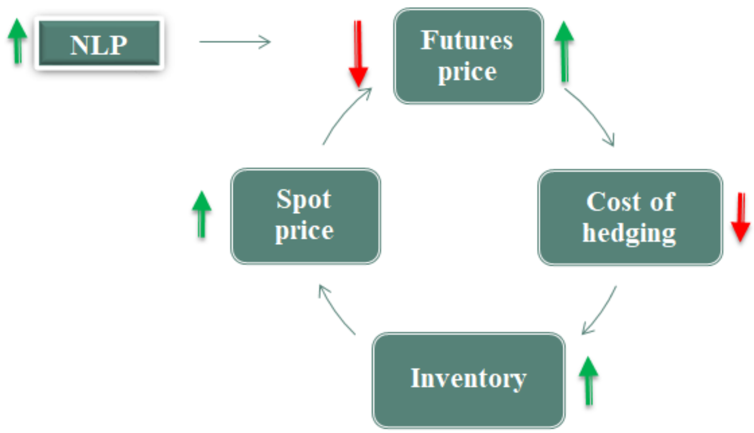
In examining the impact of financialisation, Basak and Pavlova (2016) present a dynamic equilibrium model illustrating financialisation intensifies commodity futures prices, volatilities, and correlations between commodities and equities. Similarly, Boons et al. (2012) link commodity and equity markets, by focusing on the evolving demands for hedging and speculative activities that have emerged post-financialisation. Additionally, Aït-Youcef and Joëts (2024) expands on this by introducing a theoretical framework that incorporates both chartist-fundamentalist traders and institutional investors, whose trades are driven by predictive signals in commodity markets. This model underscores the impact of index traders in amplifying correlations between commodities and equity markets.

Most of these models overlook how futures contract volatilities vary by the contract maturity, leaving a gap in understanding the direct effect of financialisation on maturities across futures contracts. Studies like Baker (2021), Isleimeyyeh (2020) and Funk (2017) attempt to bridge this gap, and it is upon these studies, *inter alia*, that our theoretical strategy is based. Notably, Kogan et al. (2009) and Baker (2021) observe that the volatility of the crude oil futures price decreases with maturity more steeply in the theoretical model than in the actual data.

In the context of market dynamics, Isleimeyyeh (2020) following Ekeland et al. (2019), develops a model that examines the interplay between physical and futures markets for commodities and their connections with equities. This 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 shows that the impact of financialisation depends on the situation of the financial investors. Moreover, an increase in the net long position taken by financial investors increases the future price, as an increase in financial investors' participation causes

[5] We deliberately do not go into detail about these theoretical models in this study due to its focus on the agricultural commodity market.

Figure 2: Net long position and futures price relationship



an increase in demand for future positions. Consequently, it leads to a decline in the cost of hedging; hence, inventory holders increase their inventory level, and spot price increases. Figure 2 draws on the above-mentioned literature to show how an increase in net long position may decrease the futures price. The inverse effect between the cost of hedging and inventory is observed when financial investors take short positions. Additionally, 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), as developed by Anderson and Danthine (1983) and Bessembinder et al. (2005). The Samuelson hypothesis states that futures volatility should increase as the delivery date draws closer. Anderson and Danthine (1983) provide a new explanation for the Samuelson hypothesis, linking degrees with uncertainty instead of time-to-maturity. As the information flow is higher nearer to the maturity date, volatility increases; therefore, the Samuelson hypothesis holds. Meanwhile, Bessembinder et al. (2005) outlines a critical condition under which the hypothesis holds—contracts where spot prices and net carry costs have negative covariance. In more recent developments, Schneider and Tavin (2024) introduce a multi-factor model combining stochastic volatility with seasonal and maturity-damping terms to address the Samuelson effect, providing a nuanced understanding of volatility dynamics as contracts approach maturity.

Overall, theoretical perspectives suggest a complex relationship between speculative activity and price volatility across different maturities. These studies highlight how financialisation impacts volatility across futures contracts, presenting varied views on how speculation influences price dynamics within and across markets.

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

While theoretical literature offers insights into financialisation's impact, a wealth of empirical research provides robust analyses of commodity futures and equity markets' interconnectedness in price, return, and volatility dimensions.[6] In this section, we examine empirical findings on cross-market interactions in commodity and equity markets. This discussion includes an exploration of differing perspectives on role of financialisation in volatility shifts, followed by a review of volatility dynamics, including an economic interpretation of the Samuelson effect and seasonality's influence on crude oil futures and equity markets.

[6]Refer to Irwin and Sanders (2011); Fattouh et al. (2013); Cheng et al. (2014); and more recent studies, such as Kupabado and Kaehler (2024), Lang and Auer (2020), and Natoli (2021), for comprehensive literature reviews.

2.2.1 Cross Market Integration

The integration between financial, energy, and agricultural futures markets, particularly post-financialisation, has become a focal point in commodity market literature. Studies by Silvennoinen and Thorp (2013) and Tang and Xiong (2012) epitomise this growing body of work, examining the heightened correlations between these markets as financialisation progressed. More recently, Tang et al. (2021) provide evidence that oil prices serve as a predictor of stock market volatility, further establishing a link between commodity and equity markets. Christoffersen and Pan (2018) also observe that price volatility of oil has become a significant predictor for the volatility of the overall stock market, especially since the financialisation era. Along these lines, Creti et al. (2013) explore time-varying correlations between commodities and equity (S&P500 Index), noting a distinct shift in the correlations between S&P500 and commodities during the 2008 financial crisis, which they attribute to the financialisation of commodity markets. This shift underscores the deterioration in diversification benefits of commodity futures as they became more closely correlated with equity markets. Additionally, Silvennoinen and Thorp (2013) reveal that the long positions (open interest) held by non-commercial traders affects cross-market correlations. In a similar vein, Milonas and Photina (2024) examine the interconnections between financial and commodity markets, incorporating global macroeconomic variables. Their findings reveal that volatility in financial markets influences the convenience yield of commodities, specifically soybeans, further tying financialisation to increased integration between these markets.

However, the aforementioned studies provide mixed results on the connectedness between the crude oil and equity markets. Many studies supporting commodities' inclusion in investment portfolios are based on data predating the global financial crisis (GFC), raising questions about their relevance in the post-GFC landscape marked by intensified financial activity in commodity markets. A significant portion of the literature overlooks volatility linkages, despite the possibility that the change in volatility of one market may affect both spot and futures prices, inventory levels, and the volatility in related markets. Thus, disregarding volatility dynamics may yield inconclusive or inconsistent results. Moreover, most of these studies fail to consider the systematic volatility patterns characteristic of commodity markets.

2.2.2 Volatility

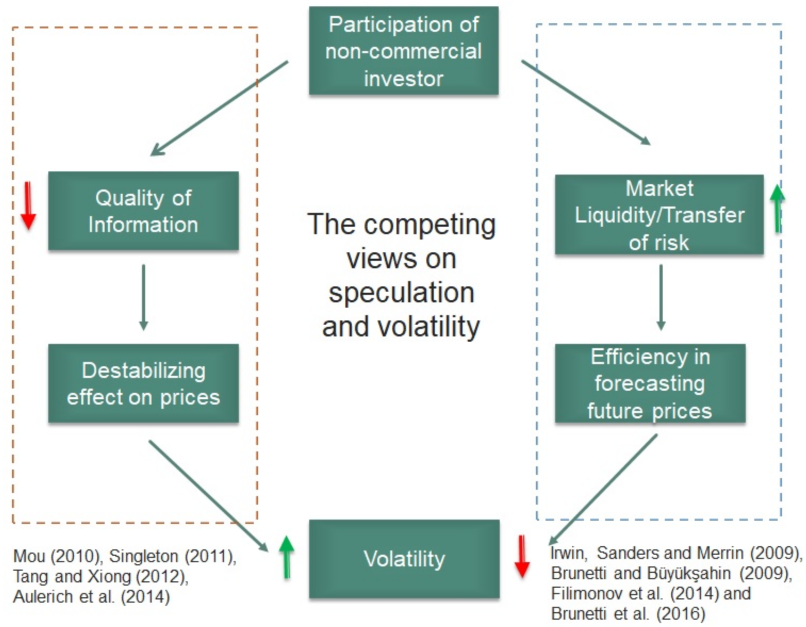
This section examines the relationship between speculation and volatility in commodity and equity markets and the evolving volatility linkages brought about by financialisation. Additionally, we review key transmission mechanisms that may facilitate the spillover of volatility from one market to another.

Most of the studies offer 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 view suggests that the increased participation of non-commercial traders reduces the quality of the information in the futures market and may exert a destabilising effect on the price, which results in increased volatility. Non-commercial traders in the market may drive prices away from equilibrium values, creating price bubbles (price boom and busts). This view is supported by studies that support the Hypothesis by Masters (2008) suggesting financialisation of commodity markets by Commodity Index Traders (CITs) was a key driver of the price bubble observed in 2007 and 2008.

Conversely, another view suggests that speculators increase market liquidity and will therefore bring efficiency to the forecasting of future prices, consequently reducing volatility. This view is supported by studies epitomised by Boyd et al. (2016) in addition to those highlighted in Figure 3. In particular, Brunetti et al. (2016) and Filimonov et al. (2014) highlight that financialisation provides liquidity to commodity markets and allows the transfer of risk among market participants, which can facilitate market forces to bring prices closer to their fundamental values.

There are several mechanisms through which volatility in crude oil and equity prices can interact, including portfolio allocations by investors, the activities of CITs, and the flow of market information. Rising crude oil prices

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



may stem from factors such as increased production costs, reduced productivity in labour and capital, diminished disposable income, lower demand for energy-intensive durable goods, or a decline in corporate earnings and equity prices. Conversely, higher oil prices can also lead to increased earnings and equity valuations within industries like mining, oil, gas, and related sectors (Nandha and Faff, 2008; El-Sharif et al., 2005). However, changes in oil prices do not always exert a clear impact on equity markets (Chen et al., 2010). For instance, a sharp oil price drop in 2016 coincided with a 9% decline in the S&P500 Index, exemplifying the potential link between commodity and equity market volatility (Maghyereh et al., 2016).

Further exploration by Chen and Mu (2021) on the return-volatility dynamics of commodities reveals a 'leverage effect' in crude oil, where volatility tends to increase following negative demand shocks. Fluctuations in crude oil prices can affect expected earnings for oil-dependent industries across both primary and secondary markets, introducing greater uncertainty into the valuation of equities tied to oil-related sectors. Specifically, Ji and Fan (2012) argue that financialisation facilitates the transmission of financial shocks to commodity markets through various portfolio reallocation strategies employed by investors. In this regard, Tang and Xiong (2012) demonstrate that CITs serve as conduits for volatility spillovers from broader financial markets into commodity markets, highlighting how shocks such as oil price fluctuations or instability in bond and stock markets impact both non-energy and oil prices through interconnected channels of stock market and dollar volatility.

From an informational perspective, volatility of an asset rather than its return is closely related to the flow of information flow within a market (Ross, 1989). Both trading volume and open interest can be used as a proxy for new information arrival.[7] This study uses open interest as a measure of liquidity.

The relationship between speculative activity and liquidity remains a point of contention. Sanders and Irwin (2010) finds a positive association between speculative activity and liquidity, while Floros and Salvador (2016) posits that the relationship between open interest and price volatility in certain contracts may be driven by speculative trading rather than liquidity provision. Kang et al. (2020) further supports this view, showing that speculators, rather than demand-side forces, often provide short-term liquidity. Given the influence of financialisation on open interest, the relationship between open interest and price volatility may vary based on market participants' positions. Overall, prior

[7]The use of trading volume as a proxy aligns with the sequential information model (Copeland, 1976) and the mixture of distribution hypothesis (Clark, 1973). Open interest, conveying information about future economic activity (Hong and Yogo, 2012), can also reflect the dispersion of beliefs among market participants (Shalen, 1993; Bessembinder et al., 1996). Together, these variables reflect overall market trading activity.

studies provide mixed and inconclusive findings on the links between price volatility and open interest.

Some studies also distinguish the effect of expected (versus unexpected) changes in trading volume and open interest on volatility (Girard et al., 2007). For example, Bessembinder et al. (1996) suggest that large unexpected changes in open interest can increase price variability, with both expected and unexpected trading volumes contributing to volatility, albeit with a stronger effect from unexpected volumes. Recent research indicates that speculators and hedgers may interpret and react to information differently, leading to distinct impacts on price dynamics based on their trading or hedging strategies. In general, non-commercial investors' participation in futures trading increases over time, especially following financialisation. Sanders et al. (2004) report that large traders (commercial) decrease their position (long position) in response to rising prices, whereas traders (non-commercial) increase their position. Likewise, Wang (2001) finds that the positions taken by both non-commercial and non-reporting investors do not drive returns, while noting weak evidence on the commercial position driving returns in selected markets.

2.3 Systematic Volatility Patterns

Commodity futures prices exhibit distinct dynamics, particularly systematic patterns in volatility, such as the time-to-maturity effect—often termed the Samuelson or maturity effect—and seasonality. The Samuelson hypothesis has been widely tested across various commodities and financial markets, yielding insights into the role of contract maturity in shaping price volatility. Although there are some contradictory results in the extant literature, the results generally produce two common conclusions. Firstly, seasonality often has a more pronounced impact than the Samuelson effect, especially for agricultural commodities (Anderson, 1985; Kenyon et al., 1987). Secondly, the Samuelson effect plays an important role in forecasting price volatility across commodities that show seasonality in demand and supply, extending to financial futures through the cost-of-carry model (Galloway and Kolb, 1996). Recognising these patterns is fundamental to understanding how speculative activity can alter the nature of volatility dynamics, a focus of this study.

2.3.1 Samuelson Hypothesis

There is a large body of empirical literature on the Samuelson hypothesis focusing on its different aspects. Research has, inter alia, tested whether: (1) shocks from the physical market influence the futures market during the near delivery date; (2) there may be a decreasing volatility pattern as maturity increases; (3) there is decreasing correlation between contracts as maturity increases; (4) shocks from the physical market may spill to the futures market in a decreasing manner; (5) trading volume and open interest affects the Samuelson pattern, (6) news arrival has influence on time-to-maturity. 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.

The *Samuelson hypothesis* refers to a phenomenon whereby volatility of the futures price increases as the contract reaches its delivery date. The phenomenon was previously suggested by Segall (1956) and Telser (1958). The basis of 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 is because nearer futures' contract prices are more sensitive to information arrival as futures converge to spot price when the contract approaches expiration, increasing the volatility of nearer contracts. Deferred contracts, on the other hand, are not affected by a large amount of information.

Prior studies show mixed results for the Samuelson hypothesis. The findings of Castelino and Francis (1982) and Miller (1979) support Samuelson's volatility hypothesis, and the effect has recently been observed for many commodities, such as energy and agricultural (see, among others, Allen and Cruickshank, 2002; Bessembinder et al., 1996; Daal et al., 2006). The effects are much weaker for metal commodities and are 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 in the time series of the volatilities across the differing maturities of futures contracts and that this leads to a decreasing pattern. In recent years, Jaeck and Lautier (2016) identify that price shocks from the physical commodity market may spill over to the futures commodity market, with a reducing magnitude when the maturity of the contract increases. The existing empirical evidence is generally based on (unconditional) variance as a measure of volatility, although some authors use the interquartile range to the same end.

Schneider and Tavin (2018) find that, for a constant period, the returns of two futures contracts 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, Phan and Zurbruegg (2020) and Phan et al. (2021) examine the Samuelson volatility effect through price-news-sensitivity and information asymmetry. However, they do not include the Samuelson correlation effect, which is important to examine when looking into the volatility link between crude oil and the equity markets. To the best of our knowledge, we are only the second (after Schneider and Tavin, 2018) to contribute to the literature by investigating the Samuelson correlation effect in the equity-commodity markets before and during the financialisation period.

The 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 contract expiry provides liquidity and, therefore, speculators can optimise their position to earn a better return in the short run. Moreover, the maturity effect is important in margin setting as, according 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 be set higher. Additionally, in the real world, volatility is neither constant (Black and Scholes, 1973) nor directly observable, due to the unobservable rate of information flow. Therefore, it is crucial to account for the maturity effect when examining the determinants of the volatility of futures prices.

2.3.2 Seasonality

This study considers the crude oil futures price, emphasising its role in price discovery and hedging against risk. Futures markets help firms to determine inventory levels based on the difference between the futures prices of subsequent months' contracts. However, without a futures market, firms must rely on their expected price changes for inventory level (Telser, 1958, pp. 234). Commodities often exhibit a seasonal pattern due to factors like harvesting seasons, and climate changes, allowing the futures price to reflect the overall supply and demand for the spot markets by indicating intra-season and inter-season variability. [8] For instance, the futures price may provide information on the next season's production and investment decision and can therefore minimise inter-seasonal price variability (UNCTAD, 2009, pp. 24). Likewise, the difficulty of determining the optimal level of production or delivery time for physical goods can be reduced by observing intra-seasonal price movement (UNCTAD, 2009, pp. 24). This suggests that seasonality is an important factor in futures price volatility and should be taken into consideration in risk management. If seasonality is not accounted for, increased price volatility due to an increase in speculative activity or other events that are sensitive to these trends may increase the overall risk in the markets.

Seasonality is a crucial factor in valuing derivatives in the agriculture and energy markets (Back et al., 2013), as the future price and volatility of such commodities exhibit seasonal patterns (Maitra, 2018; Richter and Sørensen, 2005). Seasonal fluctuation in commodity prices can be caused by many factors, such as demand for physical commodities that are affected by patterns, cycles, and trends in supply, demand, and consumption. In particular, agricultural commodity prices follow a seasonal pattern as production/harvest has a definite peak, while storage is expensive. Thus, for most agricultural commodities, price volatility appears to peak during the summer, whereas it is the high demand of winter that gives energy commodities (e.g., heating oil) their seasonality. Predictable seasonal fluctuation is reflected in prices. However, these patterns may not be perfectly predictable. Hence, from the perspective

[8] Inter-season price volatility provides information on the change in price in the long-run, whereas intra-season volatility shows information on the change in price within the growing season (Goodwin and Schnepf, 2000).

of hedgers and speculators, stochastic seasonality indicates a risk that is reflected in future prices and risk premia (Hevia et al., 2018). In general, volatility tends to be high in the presence of a demand or supply shock and when inventory is low. Auer (2014) and Hsu et al. (2014) highlights daily seasonality, and mean reversion and seasonality respectively in their crude oil research. This study uses a dummy variable to capture seasonal effects and plans to use sinusoidal functions in future research.

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; one would expect this to be exploited by arbitrageurs but, perplexingly, it is not (Malkiel and Fama, 1970). Investors should be able to build their hedging strategy to earn a higher return that is not commensurate with the degree of risk. Berument and Kiymaz (2001) show a seasonality effect (day of the week effect) in both returns and volatility on the S&P500 Index and suggest that determining the 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 that include the value effect, the size effect, the holiday effect, the weekend effect, the momentum effect, the dividend yield effect, and the weather effect. Recently, Alemany et al. (2019) assess intra-day seasonality on volatility transmission between stock indexes and show that if seasonality is neglected, the model may lose important information on volatility transmission.

It is expected that the equity market, due to its substantially larger market size, influences the commodity market through financialisation rather than the other way around, and hence it should weaken the seasonality of crude oil price volatility. Chiarella et al. (2016) and Baur and Dimpfl (2018) find that negative return shocks impact crude oil volatility more than positive shocks. Baur and Dimpfl (2018) show that post-financialisation, commodities behave more like financial assets, with volatility less influenced by underlying demand and supply seasonality. This finding is the basis of our hypothesis on financialisation weakening the seasonality of crude oil volatility.

3. DATA

For several reasons, we focus on crude oil futures for our research. WTI crude oil is the most traded contract on the NYMEX and holds the highest weight in the energy sector (25.31% as of May 7, 2020) (S&P Dow Jones Indices, 2020). Changes in crude oil prices can affect other assets, as it is a primary energy source, influencing equity markets through energy investments.

We use the S&P 500 as our equity market benchmark due to its representation of the broader economy, diverse industry mix, and tracking of the most successful companies, making it a widely accepted proxy in academia (Balcilar et al., 2019; Mensi et al., 2013; Bianchi et al., 2015).

Non-commercial traders, including money managers, hedge funds, and speculators, are viewed as financial investors in the futures market (Gorton and Geert Rouwenhorst, 2006; Haigh et al., 2005). We consider weekly data, aligned with the CFTC Aggregated Commitment of Traders (CoT) Report, available every Tuesday and published on Fridays. The CoT Report categorises positions into 'commercial' and 'non-commercial,' with further subdivisions since 2009. Using weekly data helps reduce potential biases from non-synchronous data between crude oil futures, equity markets, and CFTC data.

Lastly, we analyse crude oil aggregate open interest data to understand how liquidity impacts volatility and the linkage between crude oil futures and equities.

3.1 Crude Oil Futures & Equity Return

We use daily settlement prices of NYMEX WTI crude oil futures contracts from the U.S. Energy Information Administration (EIA) and the S&P 500 Index from Yahoo Finance[https://uk.finance.yahoo.com], covering January

5, 1993, to December 24, 2019. This timeframe allows us to evaluate the impact of financialisation on commodity and equity markets across pre-financialisation and financialisation periods.[9] The study includes monthly crude oil futures contracts with varying maturities (upto 4$^{\text{th}}$ successive delivery months following contract 1), with each contract representing 1,000 barrels of oil. We forward fill missing data from non-trading days, aligning crude oil futures with S&P 500 data, resulting in 6,795 observations. Weekly log return series are created similar to Adhikari and Putnam (2020), ending every Tuesday, to synchronise with CFTC CoT data, yielding 1,407 observations—573 for the pre-financialisation period and 834 for the financialisation period.

3.2 Measure of Financialisation through the Extent of Speculative Activity

Previous studies have used various indicators to measure financialisation. Working's "T" index, which compares non-commercial participants' activities to commercial participants' (Working, 1960), is a popular proxy for speculation but can overstate speculative activities due to the "non-reporting" category in CFTC data.[10] Other indicators include trading volume, open interest, the ratio of trading volume to open interest, the share of open interest held by non-commercials, and the difference between non-commercial long and short positions.

For this study, we use the speculation measure from Hedegaard (2011):

$$\textit{Speculation Index} = \frac{\textit{Non-commercial Long Position} - \textit{Non-commercial Short Position}}{\textit{Total Open Interest}} \tag{1}$$

This proxy is preferred because it is a relative measure (see De Roon et al., 2000), includes net non-commercial positions affected by financialisation, correlates with speculative pressure measures (Brunnermeier et al., 2008; Sanders et al., 2010), and indicates the long-term effect of speculative activity. The mentioned measure assesses whether speculators are net long or short, scaled by total open interest.

We use 2004 as the starting point for the financialisation period, following several studies that identify this year as the onset of commodity futures financialisation (Büyükşahin et al., 2010; Sanders et al., 2010; Tang and Xiong, 2012). Studies like Qadan et al. (2019) confirm a structural break around 2004 using the Chow (1960) and Bai and Perron (1998) tests. They also find a significant increase in the dynamic correlation between commodity returns and the S&P 500 Index post-2004.

For robustness (see Section 6), we also consider two other speculative measures: the ratio of speculators' long positions to total open interests and speculative pressure. The differences between these speculation measures are illustrated in Figure 4. The speculation measure we use is similar to Robles et al. (2009)

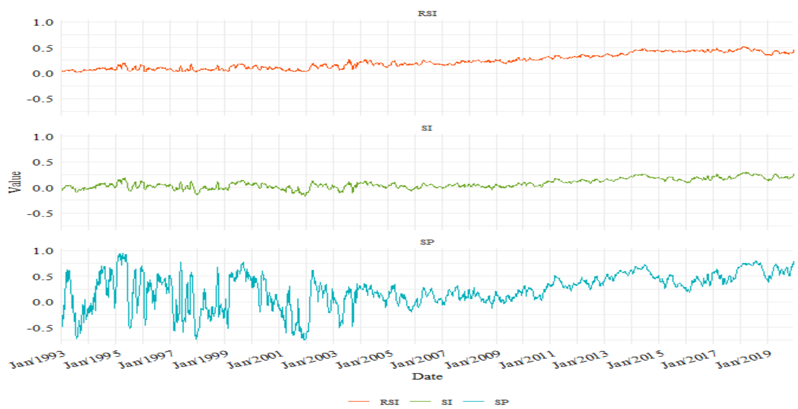
3.3 Liquidity Factor

Open interest, the total number of open contracts on crude oil futures, is reported daily and used as a powerful pro-cyclical predictor of commodity returns (Hong and Yogo, 2012). It signals macroeconomic effects and market investment changes. Aggregate open interest is a common proxy for financialization in commodity markets (Algieri and Leccadito, 2017; Fratzscher et al., 2021; Hong and Yogo, 2012) and a standard measure of liquidity (Bessembinder and Seguin, 1993; Martinez and Tse, 2008; Ripple and Moosa, 2009). We use aggregated open interest data from weekly CFTC CoT reports, converted into millions for comparison. For robustness (see Section 6), we also use detrended open interest series with quarterly dummies.

[9] We deliberately avoid creating a de-financialisation sample, as done by Adams et al. (2020), due to insufficient sample size to run DCC-GARCH and exclude the Covid period to focus on the financialisation impact only.

[10] CFTC defines non-reportable positions as the difference between total open interest and reportable positions, with unknown trader classifications (https://www.cftc.gov/MarketReports/CommitmentsofTraders/ExplanatoryNotes/index.htm)

Figure 4: Differences in Speculation Measures. SI, RSI and SP represent the speculation index, the ratio of Speculators' long position to total open interests and speculative pressure respectively.



4. METHODS

To assess financialisation's impact, we use two approaches: (i) sub-sample analysis and (ii) a commodity-specific financialisation measure. We describe our method for (1) modelling time series using our chosen econometric model, (2) examining volatility and co-movements simultaneously, and (3) extending these models to account for seasonality in commodity prices.

We employ the Vector Autoregression (VAR) - Generalised Autoregressive Conditional Heteroskedasticity (GARCH) model with Dynamic Conditional Correlation (DCC) to estimate mean and volatility cross-effects between commodity futures and equity markets, assessing the lead-lag relationship between return volatility and the impact of past volatility across markets. The DCC-GARCH model efficiently reduces parameter estimation by decomposing the variance-covariance matrix and captures the dynamic, time-varying nature of volatility correlations, offering detailed insights into the origins, directions, and intensity of volatility transmission. Recent studies have used this approach to investigate volatility spillover between oil/commodity and equity markets (Büyükkara et al., 2020; Maghyereh et al., 2017).

We use a VAR(1) process to keep the model simple, including seasonal dummies to account for exogenous seasonal impacts on asset returns and variance.[11] The VAR process involves determining lag length, estimating the model, and conducting diagnostics. Our mean equation incorporates seasonal dummies tested for significance by the likelihood ratio (LR) test. The VAR-DCC-GARCH model can be specified combining mean and variance equations. The mean equation is specified as:

$$r_t = \mu_t + \Phi r_{t-1} + \Psi d_t + \varepsilon_t; \quad \varepsilon_t | F_{t-1} \sim N(0, H_t) \tag{2}$$

where r_t is the vector of the residuals of returns, μ_t is the conditional mean vector, Ψ is vector of coefficients of seasonal dummy; $d_t = (d_t^{winter}, d_t^{summer}, d_t^{autumn})'$ is a vector where $d_t = 1$ if the season is winter, summer, or autumn and 0 otherwise, and ε_t is the vector of residuals. We use Northern Hemisphere's seasons, where winter represents (December 1 - February 28), spring (March 1 - May 31), summer (June 1-Aug. 31) and autumn (Sept. 1-Nov. 30). The variance equation is estimated as below

$$h_t = \omega + A\varepsilon_{t-1}^2 + Bh_{t-1} + \gamma d_t \tag{3}$$

where h_t is conditional variance, ω is a vector of constant terms while A and B represent parameters of the ARCH effect and represent the short-run persistence of shocks to conditional variance and parameter of the GARCH

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effect that show the long-run persistence of shocks to the conditional variance. Additionally, γ is a vector of coefficients of the seasonal dummy.

$$\varepsilon_t = H_t^{\frac{1}{2}} \upsilon_t, \upsilon_t \sim N(0,1) \tag{4}$$

The variance-covariance matrix of the residuals in the DCC is defined as

$$H_t = D_t R_t D_t \tag{5}$$

where D_t is the diagonal matrix of the time-varying standard deviations from univariate GARCH estimations and R_t is is the time-varying correlation matrix of variables. R_t is defined as

$$R_t = [diag(Q_t)]^{-\frac{1}{2}} Q_t [diag(Q_t)]^{-\frac{1}{2}} \tag{6}$$

where Q_t 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

$$Q_t = \overline{Q}(1 - \theta_1 - \theta_2) + \theta_1 \epsilon_{t-1} \epsilon_{t-1}^{'} + \theta_2 Q_{t-1} \tag{7}$$

where θ_1 and θ_2 are scalar parameters that capture the effects of past shocks and past 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. This property implies that in the event of a shock, the correlation between the underlying assets will return to its long run unconditional level. $\overline{Q}$ is an unconditional covariance matrix of standard residuals ϵ_t. To estimate pairwise conditional correlation coefficients between equity index returns and crude oil futures returns, the Quasi-Maximum Likelihood Estimation (QMLE) is used.

5. EMPIRICAL RESULTS AND DISCUSSION

5.1 Sub-Sample Analysis

This section presents our findings on the determinants of price volatility and intermarket dependencies. We begin by discussing the estimated mean and variance equations in Section 5.1.1, which describe the model's mean and variance components. We then explore the maturity effect and Samuelson correlation during both periods. Section 5.2 examines the influence of financialisation and liquidity on volatility and market integration. Each subsection includes a brief summary of results, interesting findings, and a comparison with other empirical studies.

5.1.1 Mean Estimates

The mean estimation of the model is shown in Table 1. During the pre-financialisation period, the S&P500 Index return is influenced by its own lag, consistent with Vo (2011), although this effect is absent in the financialisation period. The negative correlation coefficient suggests mean-reverting behaviour of returns, which, while weak, is statistically significant. This aligns with Junttila et al. (2018), who found a negative correlation in lagged S&P500 returns when analysing the relationship between crude oil futures, gold futures, and equity markets.

In the financialisation period, the S&P500 return is positively influenced by the lag of nearby crude oil futures returns, a 1% increase in the crude oil futures leading to a 0.31% rise in the S&P500 Index return increases the following week ($\psi_{S\&P500,CL01}$), indicating unidirectional causality (all else being unchanged). This is reasonable, given the oil sector's benefit from rising crude oil prices. However, in the pre-financialisation period, crude oil futures returns did not influence the S&P500 Index return. Moreover, in both periods, crude oil market investors do not base their decisions on past financial shocks. The nearby crude oil futures contract is influenced by its own lag ψ_{CL01} with the relationship shifting from negative pre-financialisation to positive post-financialisation, suggesting increased correlation between commodity futures returns and financialisation.

Table 1: 3: Estimates of mean equation of VARX DCC GARCH

	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)
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 for both sample periods. Before financialisation, the parameters of autumn (Φ^{autumn}) coefficients are significant at level 10% and 5% respectively for 2$^{\text{nd}}$ to 4$^{\text{th}}$ crude oil futures contracts respectively. However, these relationships are negatively correlated. As expected, we do not find any seasonal effect in the equity market return. Since financialisation, the mean return exhibits significant autumn seasonality for all crude oil futures returns. This implies that there is usually a lower return *ceteris paribus* from the crude oil futures contracts during autumn. As our main focus is on the variance part of the model, we do not go into further detail about the 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 into the time-varying integration of the equity and crude oil futures markets, which could be initiated by the financialisation of commodity markets.

Table 2: 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 3 reports the results of volatility models; this is the central point of our research. 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 parameter α quantifies the short-term volatility persistence range from $0.1116 - 0.1156$ for the S&P500 Index and $0.0206 - 0.0960$ for crude oil futures contracts. The ARCH effect (α) of crude oil futures are lower in the pre-financialisation period than in the financialisation period. As expected, we find in both periods that the ARCH effect lowers as maturity of crude oil futures increases, until it reaches the most distant crude oil futures contract; interestingly, when this occurs, the ARCH effect is found to be slightly higher than the distant contract but still lower than the front month contract. We also find parameters β to be significant at the 1% level in both markets, representing volatility sensitivity to their own past conditional volatilities. These βs range from $0.8569 - 0.8789$ for the S&P500 Index and $0.8741 - 0.9789$ for crude oil futures. In all cases, the ARCH effect is lower than the GARCH effect, implying that past variances are dominant over current variances. This indicates that conditional volatility series do not change abruptly but rather evolve steadily over a long horizon depending on past volatility. The sum of the coefficients of $\alpha + \beta$ is close to unity, which depicts that a shock to volatility in both the equity and crude oil futures market generates fairly stable results. However, $\alpha + \beta < 1$ for all assets, representing a sufficient condition for consistency and asymptotic normality of the QMLE estimator (McAleer et al., 2007).

Table 3: 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

(Continued on next page...)

Table 3: Estimates of variance equation of VARX DCC GARCH *(continued)*

	S&P500	Crude Oil 01	Crude Oil 02	Crude Oil 03	Crude Oil 04
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
	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 ω, ε_{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 the volatility of the S&P500 Index for any sample period. For the pre-financialisation period, the most distant crude oil futures contract (4^{th}) exhibits positive significant autumn seasonality. This indicates that the volatility of (4^{th}) crude oil futures is affected more during autumn than in other seasons. This is due to the fact that West Texas Intermediate (WTI) crude oil prices are in yearly peak during early autumn. As 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 autumn seasonality to be insignificantly different from zero for the most distant crude oil futures contract after financialisation. As explained in section 2, this may be due to the fact that financialisation of the commodity market diminishes the seasonality effect. As the equity market is larger than the crude oil futures market, the equity markets, post financialisation, tend to have more influence on the crude oil markets than vice versa. Thus, crude oil futures lose the commonly observed seasonal pattern in volatility and act more like a financial asset. Our finding is similar to that of Yu and Ryu (2020), the only difference being that their paper focuses on the effect of Exchange-Traded Notes (ETN) announcement on volatility of seasonal component. Overall, we can say that financialisation weakens the seasonal pattern in volatility of crude oil futures.

In both periods, the parameters θ_1 and θ_2, which are related to 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 that conditional correlation is time-varying. The only exception to this is noted in nearby crude oil futures during the pre-financialisation period. Additionally, $\theta_2 > \theta_1$, which indicates long-run persistent volatility spillover between the equity and crude oil market returns.

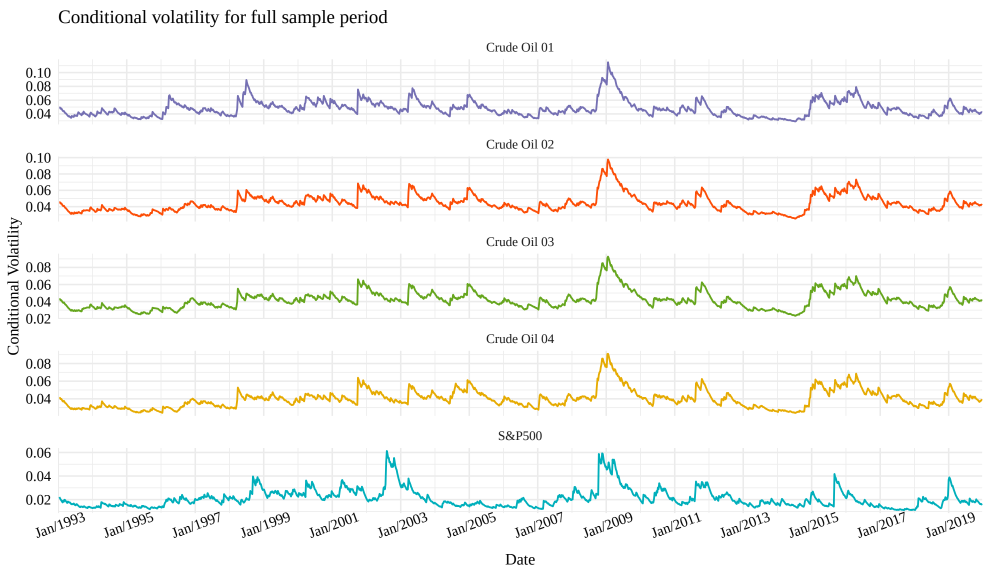


Figure 5: Conditional volatility for full sample period

Figure 5 shows conditional volatility retrieved from the VAR-DCC-GARCH model for the full sample period. There are some noticeable peaks in the conditional volatility of the equity index around mid-2001, 2008, and 2014; these correspond to various economic events. The crude oil futures market is observed to be more volatile than the equity market, however since 2004 there is more noticeable volatility in all the crude oil futures series.

5.1.3 Market Interdependence

To understand the pattern of volatility spillover from the commodity markets to equity markets, we estimate the correlation between equity markets and the respective crude oil futures market. Figure 6 plots the dynamic conditional correlations (DCC) between equity index and crude oil futures contracts at various maturities. We find that the DCC model with no lag and seasonality component presents an increased level of volatility.[12] Hence, the lower level of the volatility in DCC model can be explained by the inclusion of seasonality and the VAR component.

The level of correlation has changed widely during different periods over the last two decades, which is consistent with earlier evidence. The interdependence between equity and crude oil varies significantly over the full sample period, ranging between -0.4954 and 0.7522. However, once we divide the sample into the pre-financialisation and financialisation periods, the correlations change, indicating a development in the relationship between the equity and crude oil futures markets. The commodity-equity correlations are not stable over the whole sample period (although the DCC of all crude oil futures have almost the same movements). For crude oil futures and S&P500 Index, the correlation ranges between -0.3552 and 0.3183 during the pre-financialisation period, whereas during the financialisation period it ranges between -0.568 and 0.7915. This correlation therefore varies more in the financialisation period than in the pre-financialisation period. Overall, during the pre-financialisation period, the correlation is observed to be lower, which indicates low intrusion of financial investors in these markets. Throughout the entire 2002-2004 period, the correlation is negative, reaching -0.38 by the end of 2004. Furthermore, in 2002 there is a substantial drop in

[12]These results are available on request.

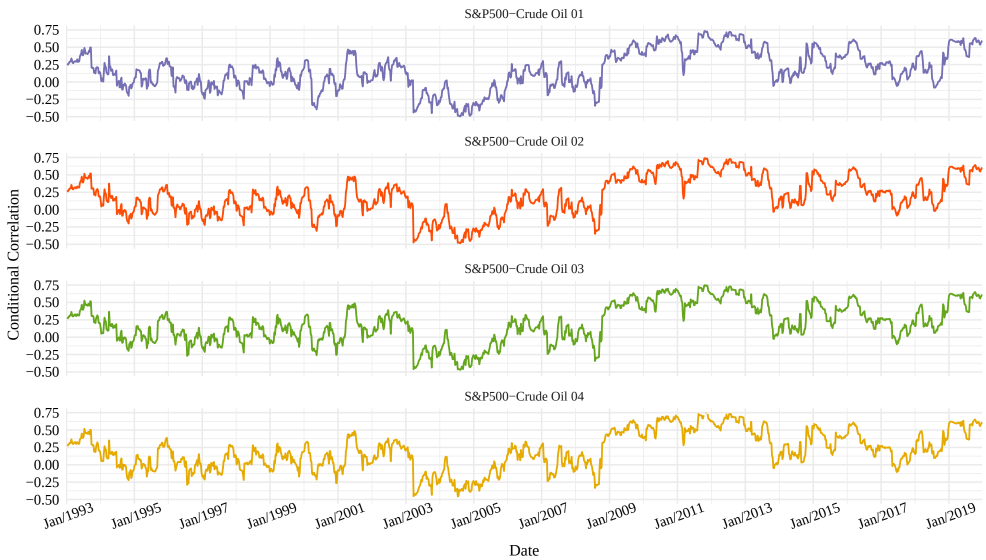


Figure 6: Conditional correlation for full sample period

correlation, which could be due to the IT bubble (also known as dot-com bubble) which coincided with September 9/11 attack. Adams et al. (2017) find a significant change in the conditional correlation between financial assets and disruptions in financial markets (structural break) during the dot-com crisis period. Antonakakis et al. (2017) reveal some interesting patterns in the connectedness between crude oil shock and stock returns during the dot-com bubble. The speculative bubble has increased both the stock price and crude oil price around this period (Miller and Ratti, 2009). Since 2004, the correlation starts to increase and remains at more or less the same level, indicating a development of similarities in increasing price dynamics between the equity and crude oil futures markets. These conclusions, although generated in a complex econometric framework of multivariate GARCH model and measured in a different scale, could also be drawn from a simple framework of unconditional correlation (available on request); this also suggests higher correlation between crude oil futures and equity markets since financialisation.

Interestingly, after the collapse of Lehman Brothers in 2008, the correlation jumps to over 0.6. This finding of dynamic conditional correlation for crude oil futures and equity is consistent with Büyükşahin et al. (2010). Moreover, Wen et al. (2012) show evidence of an increase in correlation between crude oil and the stock market after the collapse and show contagion effect exists as new information from one market has impacted the volatility of other markets. On the other hand, Forbes and Rigobon (2002) show evidence that correlation coefficients are upward biased during the period of a volatile market and find no evidence of contagion during the recent financial crisis when the effects are corrected. Creti et al. (2013) suggest that the initial decline in correlations during the financialisation period could be due to flight to quality or flight to liquidity.[13] Filis et al. (2011), on the other hand, explain this rise in correlation as due to shock in aggregate demand. Moreover, the authors state that the recession resulting from the GFC caused a drop in oil price, which can lead to an increase in the correlation. Similarly, Szafranek (2015) explains this behaviour as the herding behaviour of financial agents, with everyone heading to the exit at the same time because of the financial crisis. This correlation remains at a higher level until 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 runs contrary to the theoretical perspectives and therefore, presents evidence against the theories. The findings are, however, consistent with studies investigating the link between the S&P500 Index and energy commodities (see, for example, Filis et al., 2011; Creti et al., 2013; and Kolodzeij and Kaufmann, 2014). Junttila et al. (2018) explain this market dependency thus: low convenience yields and low interest rates attract investors, especially institutional investors, to invest in the

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

commodity futures market rather than in physical crude oil. It appears to be a natural deduction that the financialisation of commodity markets significantly affected the price dynamics of the commodity markets and, in fact, explains a strong increase in intermarket connectedness. However, we cannot ignore that global financial crisis may have triggered the cross-market contagion and may have affected the interdependency between the markets.

In 2011, there is a drop in correlation, which could be due to that fact the investors are trying to lower their risk by investing in commodities as an asset class. Szafranek (2015) suggests the drop in interdependency may be due to the Dodd-Frank Wall Street Reform and Consumer Protection Act (henceforth, Dodd-Frank Act), which was introduced in 2010 with the intention of making momentous changes to the financial regulation of the commodity markets.[14]. In 2013, the correlation falls significantly before starting to increase in late 2014; this corresponds with Junttila et al. (2018).

Büyükşahin and Robe (2014) present empirical evidence specifically regarding the activity of traders who trade both equities and crude oil, thereby increasing cross-market linkage in the rates of return for equities and crude oil futures. Hence, in a contango market, these traders are more likely to increase their positions in crude oil. The hypothesis on the net long positions of the trader during the period are tested in the Granger causality test (see section 5.2.2). Moreover, the higher correlation between the equity and crude oil futures markets suggests greater interdependence between these markets, implying potentially greater spillover from one market to the other. However, the correlation might not provide a definitive answer to the direction of that spillover; therefore, further analysis is required to ascertain the direction of interaction between the financial and commodity markets.

5.1.4 Sensitivity Over Time

We test whether the mean of dynamic conditional correlation varies from the pre-financialisation period to the financialisation period (as per Manera et al., 2013a). We find all t-statistics are significant at 1% level except for correlations between distant crude oil futures and the most distant crude oil futures.[15] The result implies that all mean values of ρ are different during the pre-financialisation and financialisation periods. In particular, the mean values between the equity index and crude oil futures are much higher after financialisation than during the pre-financialisation period. This result confirms that there is increasing connection between the equity and crude oil futures markets. Moreover, dynamic conditional correlation among assets with different maturities increases after financialisation.

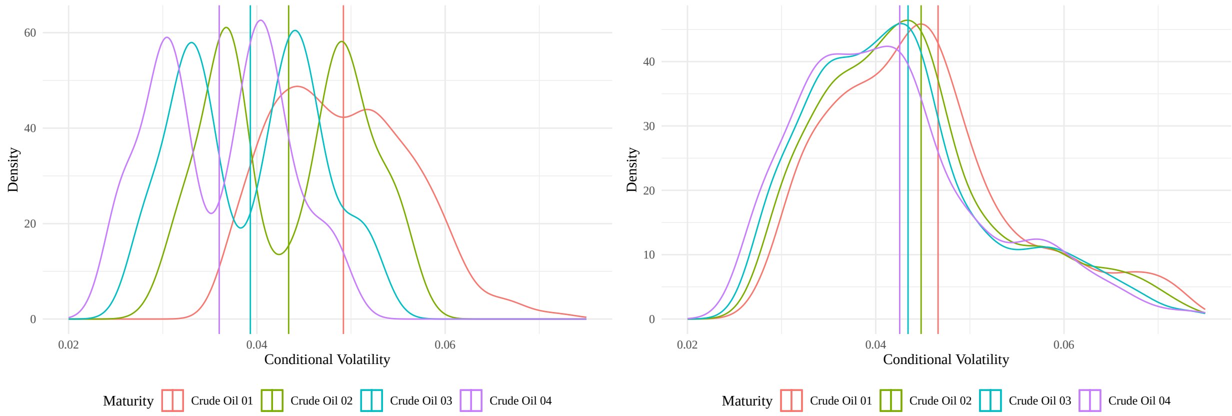
5.1.5 Samuelson Effect

One of the most important features of commodity futures prices is the variation in the price of nearby and deferred contracts. These variations in price behaviour result in a decreasing volatility pattern, i.e., long dated commodities are more volatile than short dated ones. Moreover, a 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 the Samuelson hypothesis (Samuelson, 1965). These systematic patterns are broadly discussed in this section.

Samuelson Volatility Effect There are several methods for performing the Samuelson hypothesis test. Walls (1999) performs linear regression using high/low price to measure price volatility as a function of the 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 comparing these (see Lautier and Raynaud,

[14]The Dodd-Frank Act was initiated to promote transparency in the markets and to restrict excessive speculation in the energy derivatives market. In section 737 of the Act on position limits, CFTC proposed regulations to maximise practicability (i) 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 are available at https://www.govinfo.gov/content/pkg/PLAW-111publ203/html/PLAW-111publ203.htm

[15]Results are available on request.



(a) Pre-financialisation period **(b)** Post-financialisation period

Figure 7: Distribution of conditional volatility for crude oil futures contracts

2011). The distribution of conditional volatility of crude oil-equity is shown in Figure 7. This figure illustrates how the conditional volatility changes over different maturities. In Figure 7a, before the financialisation period, the distribution of conditional volatility shows two peaks in distribution, which suggest that volatility was concentrated in two areas for all crude oil futures contracts. On the other hand, in Figure 7b which covers the financialisation period, the volatility seems to have one particular peak with a wider range. Moreover, the distribution exhibits shifts to the right after financialisation. This implies an increase in conditional volatility. Furthermore, the mean of h_{CLF} during the pre-financialisation period ranges between 0.0360 and 0.0492 whereas the mean of h_{CLF} after financialisation ranges from 0.0425 to 0.0466. During the period of global financial crisis, the maximum value of h_{CLF} is 0.1227.

We also observe that during the pre-financialisation period, the mean of conditional volatility of nearby crude oil futures is higher than the mean of the most distant contract, suggesting that as maturity increases, the conditional volatility of the contract decreases. The result supports *Samuelson maturity/volatility effect* for all four crude oil futures contracts. We can say time-to-maturity explains part of the volatility. Even though there is an overall increase in conditional volatility in the financialisation period, the mean of nearby crude oil futures is found to be lower after financialisation. Overall, we find the maturity effect to be diminishing after financialisation, as the most distant contract's conditional volatility is more increased (0.0065) than that of the next-to-nearby contract (0.0014) after the financialisation of the commodity markets. The reason behind this diminishing Samuelson hypothesis could be because market liquidity has a stronger effect on the volatility of nearby contracts than on distant contracts, which could decrease the volatility of nearby contract more, as was shown in section 5.2.1.

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-financialisation and financialisation periods. D-statistics for the Kolmogorov-Smirnov test are reported in Table 4. The Kolmogorov-Smirnov test demonstrates that the distribution of conditional volatility from DCC for crude oil futures during the pre-financialisation period significantly differs from that of the crude oil futures after financialisation.

In order to further look into the Samuelson phenomenon, we utilise the non-parametric test developed by Jonckheere (1954) and Terpstra (1952); this is necessary because Samuelson hypothesis testing requires the testing of the order of volatility among different contracts with different expiry dates. Our test differs from that of Duong and Kalev (2008) and Jaeck and Lautier (2016) in that we use weekly conditional volatility extracted from the VARX-DCC-GARCH model, rather than the natural logarithm of daily volatility. Moreover, our estimated volatility captures seasonality. We apply the Jonckheere-Terpstra (JT) test to investigate the null hypothesis that the volatilities of all crude oil futures contract series are equal, against the alternative hypothesis that posits that higher volatility is observed in nearby crude oil futures contract series. The null and the ordered alternate form (where one must observe

Table 4: 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.

at least one strict inequality) of the JT test can be described as follows:

$$H_0 : \sigma_k = \sigma_{k-1} = \ldots = \sigma_1 \; vs. \; H_1 : \sigma_k \leqslant \sigma_{k-1} \leqslant \ldots \leqslant \sigma_1$$

where k is the number of futures time series and σ_1 is the median of the conditional volatility of the time series based on the contracts nearest to maturity; σ_2 is the median of the conditional volatility of the time series based on contracts second closest to maturity, and so on. The statistics from the Jonckheree-Terpstra test are reported in Table 5. In both the pre-financialisation and the financialisation periods, the null hypothesis is rejected, which confirms there is higher volatility in nearby futures contracts than in distant contracts. This evidence confirms that the *Samuelson maturity effect* holds for crude oil futures contracts in both sample periods, which implies that the maturity effect is unaltered even after the financialisation of commodity market. Moreover, the evidence suggests that the Samuelson hypothesis is robust in the crude oil futures market even after controlling for seasonality. The result is consistent with the findings of Jaeck and Lautier (2016) that the Samuelson hypothesis holds for WTI crude oil markets. However, this outcome is contrary to that of Duong and Kalev (2008) who find that the Samuelson effect does not appear to hold in the NYMEX crude oil futures market.

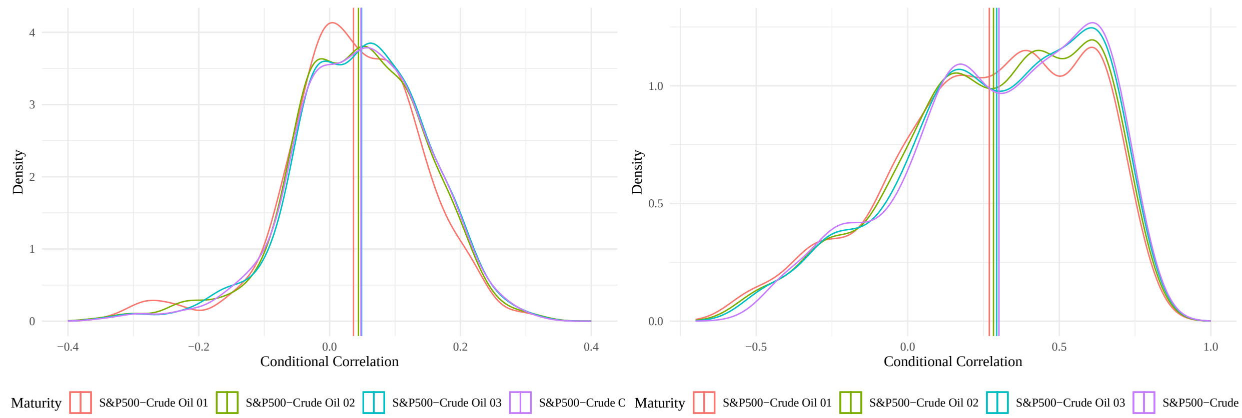
Table 5: Testing for the Samuelson Effect Using the Jonckheere–Terpstra Test on Conditional Volatility

	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 the Jonckheere–Terpstra test on conditional volatility of crude oil futures during the pre- and post-financialisation periods. h_1 (h_k) is the overall median for conditional volatility of crude oil futures, where k denotes the k-closest contract to maturity.

As the non-parametric tests are less powerful than the parametric tests, we also use linear regression with conditional volatility to examine the Samuelson hypothesis. The correlation coefficient of the speculation index with conditional volatility from Table 8 shows that after financialisation, the nearby crude oil futures coefficient (0.005) is higher than that of the distant crude oil futures contract (0.002). However, the results are insignificant so we cannot rely on regression analysis to assert that financialisation impacts more on the nearby crude oil futures contract than on the distant contract.

Samuelson Correlation Effect Turning now to the evidence on conditional correlation, Figure 8 compares the distribution of the correlation of crude oil-equity during the pre- and financialisation periods. Moreover, it depicts how the correlation changes over different maturities. Before financialisation, as shown in Figure 8a, the range of the distribution of correlation (−0.355 to 0.318) is lower than during the financialisation period (−0.568 to 0.792),



(a) Pre-financialisation period **(b)** Post-financialisation period

Figure 8: Distribution of conditional correlation for crude oil

as shown in Figure 8b. The distribution exhibits shifts to the right when passing from the pre-financialisation to financialisation period. This implies an increase in conditional correlation between the commodity and equity markets. The mean of pre-financialisation correlation is between 0.0365 and 0.0488, which is lower than the mean correlation of financialisation period (0.269 to 0.3009 which also confirms an increase in correlation after 2004). Overall, the correlation of the distant contracts with the equity market has increased more than that of the nearby contracts.

Furthermore, we observe during both periods that the mean of correlation between crude oil futures decreases as maturity of the contract increases. For instance, the mean of correlation between the nearby and next-to-nearby crude oil futures contract is 0.968 (pre) and 0.991 (post), whereas the mean of correlation between the nearby and most distant crude oil futures contract is 0.927 (pre) and 0.969 (post), both of which are lower (0.041-pre and 0.022-post). This indicates that correlations become less dependent on maturity as maturity increases and moves away from the first underlying contract; this is analogous to the *Samuelson correlation effect*. These results are consistent with the findings of Schneider and Tavin (2018) on the Samuelson correlation effect, in that they observe a decreasing dependence pattern as the difference between the expiry dates of the futures contracts increases.

What is surprising is that we reject the effect of the *Samuelson correlation effect* when we investigate the correlation effect in crude oil-equities. Before financialisation, the mean of correlation of nearby crude oil futures and S&P500 ($\rho_{S\&P500-CLF01}-$ 0.0365) is lower than the mean of correlation of the most distant crude oil futures and S&P500 ($\rho_{S\&P500-CLF04}-$ 0.0479). This indicates that the correlation of crude oil futures and S&P500 increases as the maturity of crude oil futures increases. In particular, we find this relationship to be more prominent after financialisation; that is, the mean of correlation of nearby crude oil futures and S&P500 ($\rho_{S\&P500-CLF01}-$ 0.269) is lower than the mean of correlation of the most distant crude oil futures and S&P500 ($\rho_{S\&P500-CLF04}-$ 0.3009).

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

$$H_0 : \rho_k = \rho_{k-1} = \ldots = \rho_1 \; vs. \; H_1 : \rho_k \geqslant \rho_{k-1} \geqslant \ldots \geqslant \rho_1$$

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 based on contracts nearest to maturity; ρ_k is the median of the conditional correlation of the time series of kth maturity based on the most distant contracts to maturity. Table 6 reports the statistics of the JT test. Before financialisation, the test is at 5% significance level; whereas after financialisation the test is significant at 1% level, providing evidence for our prior observation that the correlation effect runs contrary to Samuelson. In particular, it shows that the opposite effect is more prominent in the financialisation period. This result may partly be explained by the role of financialisation, as financial investors are investing in more contracts with longer maturity horizons; thus the correlation between equity and crude oil futures with higher maturity are becoming more integrated.

Table 6: 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 the Jonckheere–Terpstra test on conditional correlation of crude oil futures during the pre- and post-financialisation periods. ρ_1 (ρ_k) represents the overall median for conditional correlation of the S&P500 and crude oil futures, where k denotes the longest contract to maturity.

With regard to testing for an overall change in distribution between the sample periods, we use the Kolmogorov-Smirnov test on conditional correlation; this is shown in Table 7. As can be seen from the table, the distribution of conditional correlation between S&P500 and crude oil futures during the pre-financialisation period varies from that of the crude oil futures after financialisation.

Table 7: 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 the Kolmogorov-Smirnov test on conditional correlation between the S&P500 and crude oil futures contracts during the pre- and post-financialisation periods.
* ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels.

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

5.2 Impact of Financialisation via Commodity-Specific Measure

The first set of analyses examines 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 a speculative index measure and open interest. This analysis provides further understanding of the dynamics of correlation and volatility, allowing us to examine whether commodities can be beneficial for diversification during the financialisation period.

5.2.1 Regression Analysis

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-financialisation and financialisation periods. The results of the regression analysis are set out in Table 8. The coefficient of the speculation index (ζ_1) is negative and significant for the nearby crude oil futures contract. This indicates that a change in speculative activity contributes to explaining the change in the volatility of nearby crude oil futures contracts. The interpretation of this result is that an increase in speculative activity leads to lower price volatility in nearby crude oil futures. However, in the financialisation period, the 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 et al. (2013b) suggest that long term speculation has either negative or insignificant effects on volatility. It is an open question whether speculation can counteract the excess volatility of a crisis period. We observe that the relationship between speculative activity and the volatility of the equity market and the crude oil futures market goes in opposite directions during the two sampled periods, which shows that the impact of speculation varies for the pre-financialisation and financialisation periods. A plausible explanation for the changing nature of the volatility dynamics during the pre-financialisation and financialisation windows for crude oil futures could be attributed to their relationship with the equity market over those two periods.

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

Link between Correlation and Speculative Activity and Open Interest To explore the relationship between financialisation, liquidity, and change in correlation between the crude oil-equity markets, we use regression analysis. Table 9 shows the result of the regression analysis. We do not observe statistically significant correlation between speculative activity change and change in correlation of the equity and crude oil futures markets during either the pre-financialisation or financialisation period. However, there is a difference in the direction of relationship between the two periods. Similarly, we find insignificant results for a change of interest impacting on change in correlation of equity and crude oil markets.

Thus far, we have focused on regression analysis to investigate the effect of financialisation on the crude oil futures and equity markets. Overall, our results suggest that financialisation has changed the results between pre-financialisation and financialisation.

5.2.2 Granger-Causality Analysis

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

Table 8: Regression results (SI and OI on conditional volatility)

	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}
ζ_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)
ζ_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: $h_{ij,t} = \zeta_0 + \zeta_1 SI_i + \zeta_2 OI_i + e_{ij,t}$, which examines the impact of speculative activity and open interests on conditional volatility of equities and commodities during pre-financialisation and financialisation periods. Standard errors $e_{ij,t}$ in parentheses. h, ζ_0, ζ, CLF, SI, and OI represent conditional volatility, constant term, coefficient, crude oil futures, speculation index, and open interest, respectively. The speculation index is measured by $\frac{\text{Non-commercial Long Position} - \text{Non-commercial Short Position}}{\text{Total Open Interest}}$ following Hedegaard (2011). ***, **, and * denote statistical significance at 1%, 5%, and 10% levels.

Table 9: Regression result (SI and OI on conditional correlation)

	Dependent variable:							
	pre-financialisation period				financialisation period			
	$\rho_{S\&P500\text{-}CLF01}$	$\rho_{S\&P500\text{-}CLF02}$	$\rho_{S\&P500\text{-}CLF03}$	$\rho_{S\&P500\text{-}CLF04}$	$\rho_{S\&P500\text{-}CLF01}$	$\rho_{S\&P500\text{-}CLF02}$	$\rho_{S\&P500\text{-}CLF03}$	$\rho_{S\&P500\text{-}CLF04}$
$\eta_1 SI$	-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 represent conditional correlation constant term, coefficient, crude oil futures, speculation index, and open interest respectively. Speculation index is measured by $\frac{\text{Non-commercial Long Position} - \text{Non-commercial Short Position}}{\text{Total Open Interest}}$ following Hedegaard (2011). ***,**, and * denote statistical significance at 1%, 5%, and 10% level.

Speculative Activity and Volatility It is of interest to know whether speculative activity can be used in forecasting the volatility of subsequent markets or if investors change their position based on past information on volatility. Hence, we examine whether speculative activity in the futures markets can influence the conditional volatility of the equities and crude oil futures markets, and vice versa. The results are presented in Table 10. The evidence indicates that there is unidirectional causality from speculative activity to conditional volatility of S&P500 and the crude oil futures contract for the full sample during the financialisation period. This suggests that non-commercial traders do not follow trends; rather they drive volatility to fluctuate over the entire period and during the financialisation period. However, for the pre-financialisation period, there is no significant Granger causality link between conditional volatility and speculative activity in either direction.

These findings reveal that financialisation, measured by long term speculation, leads to volatility in both the equity and crude oil futures markets. Hence, we may say that speculative trading may drive volatility to change in the long run. This outcome runs contrary to the findings of several studies, such as Sanders et al. (2004) and Büyükşahin and Harris (2011) who suggest that speculation does not precede price volatility. Moreover, Algieri and Leccadito (2019) find the effect of long-run speculation Granger-causing conditional volatility of crude oil futures to be insignificant, which does not appear to be the case in our findings. However, their result shows evidence that speculation Granger-causes conditional volatility in some other energy commodities. Our result may be explained by the fact that we incorporate seasonality in conditional volatility and we use a speculation index that is highly correlated with speculative pressure, thereby increasing the predictive power of the speculation index on volatility. These results are consistent with Hamilton (2009a) and Singleton (2014), who find that speculation drives price fluctuation in oil markets. This observation supports our hypothesis that financialisation or a measure of speculative activity may lead the volatility of crude oil futures prices.

Table 10: 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 the speculation index during the pre-financialisation and financialisation periods. h, CLF, and SI represent conditional volatility, crude oil futures, and the speculation index, respectively. The speculation index is measured by $\frac{\textit{Non-commercial Long Position} - \textit{Non-commercial Short Position}}{\textit{Total Open Interest}}$.

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

Liquidity and volatility Turning now to the analysis of the impact of $(OI_{i,t})$ on the conditional volatility $(h_{ij,t})$ of the equity and the crude oil markets. The results from the Granger Causality test are presented in Table 11. The results indicate that Granger causality persists from open interest to conditional volatility of equity and the nearby crude oil futures during pre-financialisation. However, as the maturity of the crude oil futures contracts increase, open interest loses a causality link on the volatility of distant contracts. This suggests that nearby contracts are more liquid than deferred contracts; thus open interest has more predictive power on nearby contracts than on deferred contracts. In additional, the result shows that conditional volatility does not have forecasting power on open interest, which is consistent with the findings of Fung and Patterson (1999). Investors tend to make decisions based on liquidity rather than on price fluctuation information during the pre-financialisation period.

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

Table 11: 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 differences of conditional volatility and open interest during the pre-financialisation and post-financialisation periods. h, CLF, and OI represent conditional volatility, crude oil futures, and open interest, respectively.

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

Speculative Activity and Correlation To gain information for how conditional correlation ($\rho_{ij,t}$) between the crude oil futures and the equity markets are linked to speculative activity, we carry out a Granger Causality test. The results are shown in Table 12. We barely find evidence of Granger causality from the speculation index to conditional correlation. For instance, during the financialisation period, speculative activity may lead co-movement between equity and the 2^{nd} to 4^{th} month crude oil contracts. While this result is significant at 10% level of significance, overall, these results must be interpreted with caution. Hence, we cannot confirm that speculative activity causes correlation to change after financialisation. There is a minor indication that financialisation may drive co-movement between these markets to change but further analysis should be undertaken to confirm whether the co-movement is due to change in speculative activity.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 12. 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^{nd} – 4^{th} month crude oil contracts. However, the results is significant at 10% level of significance. 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.

Liquidity and Correlation The Granger causality between conditional correlation and open interest is less pronounced than that between volatility and open interest. The results are reported in Table 13. In the pre-financialisation period, there is no causality found between a change in conditional correlation and a change in open interest in any direction. However, we find that conditional correlation may lead open interest after financialisation. In particular, we find the

Table 12: 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 the speculation index during the pre-financialisation and post-financialisation periods. ρ, CLF, and SI represent conditional correlation, crude oil futures, and the speculation index, respectively. The speculation index is measured by $\frac{\textit{Non-commercial Long Position}-\textit{Non-commercial Short Position}}{\textit{Total Open Interest}}$.

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

Granger causality between open interest and conditional correlation of equity and the 2[nd] − 4[th] month contracts to be significant. This relationship is significant at 10% level and hence, there is a possibility that liquidity does not directly change the correlation between these markets.

Table 13: 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 open interest during the pre-financialisation and post-financialisation periods. ρ, CLF, and OI represent conditional correlation, crude oil futures, and open interest, respectively.

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

The results in this study indicate that the volatility linkage between the crude oil futures market and the equity market has changed considerably since 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 the commodity futures market, thereby 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 the equity and the crude oil futures markets. In most cases, as hypothesised, we find distinct results for nearby contracts and deferred contracts (see section 5.1.5). This could be due to the fact that the front month contract's price reflects the spot price. In section 5.2.2, we find evidence that since financialisation, open interest and volatility has a bilateral causal relationship. As hypothesised, we find the seasonality effect to be not present in volatility in financialisation period. Moreover, the Samuelson maturity effects holds in the crude oil futures market. Interestingly, the effect starts to decrease after financialisation and the difference in volatility among crude oil futures contracts starts to reduce. The most striking results to emerge from the analysis indicate an opposite effect of Samuelson correlation between crude oil futures-equities, a negative effect that becomes more noticeable after the financialisation of commodities.

6. ROBUSTNESS CHECK

In order to analyse if the main results vary under several conditions, we focus on three types of robustness check: we assess whether the results are unaffected when alternative GARCH models are adopted, we check if using a different measure of speculation changes the result, and we test whether detrending a data series changes the result for the 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 et al. (2009).[16]. The second measure is calculated as the speculative pressure following De Roon et al. (2000) and Sanders et al. (2004).[17] 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.[18]

7. CONCLUSION

The paper analyses how financialisation shapes the volatility connectedness between the equity and the crude oil futures markets, thereby offering new insights into the mechanism underpinning crude oil-equity interdependence. By employing a VAR-DCC-GARCH framework with seasonality as an exogenous variable, supplemented with regression and Granger causality analyses, our findings highlight several key economic channels and policy implications that demand further scholarly attention.

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 much of the previous work in Forbes and Rigobon (2002), who suggest that cross-market interdependence depends on market volatility and thus its correlation is inclined to increase during highly volatile periods. This increased correlation deteriorates the diversification benefits traditionally associated with crude oil futures markets. The underlying mechanism can be explained through the lens of portfolio rebalancing, for instance, in times of increased volatility, market participants often liquidate positions across various assets—equities and commodities alike—to meet margin requirements or to consolidate liquidity, thereby aligning price dynamics across markets. Moreover, the inter-market dependence in terms of volatility suggests that either market can influence the other market to fluctuate. Hence, investors can use this information in their trading strategy.

Our results further suggest that the seasonal effect weakens and fades away for both return and volatility since the financialisation, indicating that crude oil futures increasingly resemble financial assets. Although the Samuelson volatility effect holds in both the pre-financialisation (1993-2003) and financialisation (2004-2019) periods, the effect is found to diminish in the financialisation period. This indicates that the market structure has evolved, with speculative

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

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

[18] Robustness check results are available on request.

participation and short-term trading strategies gaining prominence and redefining the key drivers of price movement. Surprisingly, we find an "inverse" effect of Samuelson correlation on the linkage between crude oil futures-equity, i.e., stronger correlation between crude oil-equity with deferred contracts than nearby contracts- reinforces the notion that the hedging horizon and rolling strategies of institutional investors can systematically affect cross-market linkages. In essence, as participants roll over contracts and reposition along the futures curve, the temporal structure of both risk and correlation shifts, shaping volatility co-movements in ways not fully captured by conventional models. This suggests that systematic patterns of volatility should not be overlooked when forecasting volatility/co-movement, particularly when the market is highly volatile or in a crisis period. Further, this highlights the importance of incorporating contract maturity structures into risk management and policy approaches to mitigate systemic spillovers.

While our analysis suggests the existence of higher price volatility and co-movements among equities and crude oil futures since financialisation, the commodity-specific measures of financialisation do not confirm such a direct impact on either volatility or correlation. Rather, the influx of non-commercial investors-often linked with index-based strategies or speculative flows seems to increase the open interest, which provides liquidity and/or increases informational market efficiency. This finding is similar to Bohl et al. (2023) who find that financialisation enhances the efficiency of index commodity futures markets through higher CIT activity linked to improved informational efficiency, yet stand in contrast to Brogaard et al. (2019); Coles et al. (2022); Bond and Garcia (2022), which suggest index investing reduces the information efficiency. From the standpoint of microstructure theory, enhanced liquidity reduces transaction costs (see Kyle (1985); Glosten and Milgrom (1985); Glosten et al. (2021)) and fosters more efficient price discovery, thereby dampening volatility over the long term. Consequently, financialisation emerges as a double-edged phenomenon: it integrates crude oil and equity markets more closely, intensifying price spillovers, but also encourages the development of deeper, more liquid markets that can moderate excessive price swings. This underscores the intricate interplay between liquidity-driven stability and contagion-driven volatility. Understanding these opposing forces is crucial for designing balanced regulatory policies and for refining risk management strategies that can navigate the increasingly complex landscape of global asset markets.

The findings presented here opens several avenues for ongoing research. Extending the analytical framework to additional commodity classes—such as, index and off-index, agricultural products or metals—would help determine whether similar co-movement mechanisms, liquidity channels, and financialisation effects apply beyond crude oil. Employing high-frequency data could offer a more granular perspective on the near-instantaneous spillovers of shocks and news across interlinked markets. Moreover, as global economies transition toward low-carbon energy sources, examining the impact of green finance and shifting energy demands on commodity–equity correlations becomes increasingly critical. Finally, incorporating geopolitical shocks and long-run macroeconomic variables would enhance our understanding of the multifaceted forces influencing commodity market dynamics in a rapidly transforming global landscape.

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