Samuelson and Co - Revisiting the Relationship between Equity and Commodity Markets: It's Complicated

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Abstract

This paper presents an analysis of commodity pricing within a unified framework that allows us to examine the interaction of (i) seasonality, (ii) the Samuelson maturity effect, (iii) the Samuelson correlation effect, and (iv) the increasingly stronger connection to equity markets. Our first key finding reveals that index commodities exhibit greater volatility compared to off-index commodities. Secondly, financialisation attenuates seasonality in price volatility for certain index commodities. Thirdly, the Samuelson (1965) maturity effect, which suggests lower volatility in longer-dated contracts, still holds but has weakened since financialisation. Finally, no Samuelson correlation effect is observed between equity and commodity markets following financialisation.

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1. Introduction

Commodity markets are characterised by complex and multifaceted dynamics that drive their behaviour and influence price movements. These dynamics arise from a combination of key factors, including (i) supply and demand, (ii) speculation and financialisation, (iii) globalisation, and (iv) geopolitical events. At the core, the balance between supply and demand plays a crucial role in determining commodity prices. For instance, changes in production levels, natural disasters, and trade policies affect supply, while demand is influenced by consumption trends, technological advancements, and global economic conditions. These imbalances, however, are further exacerbated by speculation and financialisation, where futures markets introduce significant volatility as investors engage in speculative trading, often amplifying price fluctuations.

Globalisation adds another layer of complexity, as commodities are deeply embedded in international trade networks and susceptible to the economic policies of major importing countries. Changes in global demand, influenced by the growth trajectories of key economies, directly impact commodity markets, particularly in energy, agriculture, and metals. Geopolitical events, such as conflicts, trade embargoes, or sanctions, also play a significant role, especially in energy markets like oil, where tensions in critical producing regions can lead to sharp price increases.

Beyond these external dynamics, commodity markets exhibit distinctive behavioural patterns, based on their type - whether agricultural (grains or softs), livestock, energy, metals - and their classification as either index (included in the Goldman Sachs Commodity Index (SP-GSCI) and Dow-Jones UBS Commodity Index (DJ-UBSCI)) or off-index (not included in those indices) commodities, mean-reversion, seasonality, and the Samuelson maturity and correlation effect, which contribute to their inherent volatility and challenge the applicability of the Efficient Market Hypothesis (EMH). Mean-reversion refers to the tendency of commodity prices to fluctuate around a long-term average, with prices eventually reverting to their fundamental levels despite short-term disruptions from supply shocks or geopolitical events. This characteristic is particularly relevant in commodities where price corrections are expected after deviations from their fundamental values.

Seasonality also plays a key role, particularly in agricultural and energy markets, where predictable patterns—such as the effect of planting and harvesting seasons or weather-related demand for heating oil and gasoline create cyclical price movements. Storage and inventory levels also fluctuate seasonally, with low-demand periods leading to inventory build-ups and price declines. This characteristic of commodity futures make it challenging for traditional notions of the market efficiency hypothesis to hold.

The Samuelson (1965) maturity effect, or the increased volatility as futures contracts approach expiration, further complicates price behaviour. As futures prices converge with spot prices, the market experiences increased uncertainty, particularly in sectors sensitive to seasonal and weather variations. Schneider and Tavin (2018) refers to the Samuelson correlation effect as a decrease in the correlation between the returns of two futures contracts as the maturity of the second contract increases and diverges from that of the first contract. This effect is often magnified by the availability of new information as contract expiration nears, leading to rapid price adjustments and short-term volatility spikes.

In light of these complexities, forecasting commodity prices or volatility becomes a challenging endeavour. The increasing financialisation of commodities, where market dynamics are heavily influenced by broader financial markets; especially equity markets adds an additional layer of intricacy. As a result, the interplay of these factors creates a commodity market that is not only highly volatile but also difficult to predict, with far reaching implications for industries and economies that rely on stable commodity prices.

Since the early 2000s, there has been a substantial increase in "non-commercial" participants in commodities futures markets (Frenk, 2010). This increased participation, often referred to as the financialisation of commodity markets, presents researchers with the opportunity to explore the effect of investors (speculators) in markets where they previously played a minor role. Financialisation has coincided with a period marked by rising prices and volatility in various commodities (Dwyer et al., 2011). Simultaneously, there appears to be an increasing correlation observed both among commodities (Tang and Xiong, 2012)[1] and between equity and commodities (Büyükşahin and Robe, 2014).[2] The "smoking guns" begs the question of if, and how, financialisation has impacted the relationship between commodity futures and equity markets.

Empirical findings on the impacts of financialisation are mixed. Some argue that the increase in price volatility and co-movement between equities and commodities can be attributed to financialisation (among others, Masters, 2008; Tang and Xiong, 2012), while others suggest these dynamics are driven by economic fundamentals and business cycle (including Fattouh et al., 2013; Hamilton, 2009; Kilian and Murphy, 2014).[3] Surprisingly, the discussion on the financialisation of commodity markets has largely overlooked seasonality and the Samuelson effect, despite the fact that seasonality is a persistent feature in many commodities. Incorporating this volatility pattern is essential due to its implications for the production, consumption, and pricing processes of commodity-related contracts (Schneider and Tavin, 2024). This oversight is significant because regular seasonal patterns in commodity demand and supply can influence spot prices, which in turn may affect the term structure of futures prices. This also brings attention to the Samuelson hypothesis. Additionally, seasonality is also evident in equity markets as calendar effects, such as day-of-the-week or month-of-the-year effects.

In this paper, we look at volatility dynamics of commodity futures markets and their

[1] Tang and Xiong (2012) present a seminal analysis in this area, but they do not consider the well known seasonality that is present in the data.

[2] In general, non-commercial investors are the speculators who use derivatives markets to speculate on the direction of futures price movement, while commercial investors are the hedgers who use derivatives market to hedge price risk. It should be acknowledged that in some cases, hedgers also enter the futures market to speculate or to seek arbitrage.

[3] see, Irwin and Sanders (2011); Cheng et al. (2014) and Natoli (2021) for extensive literature on financialisation of commodity markets.

return volatility connectedness with equity market in terms of financialisation of commodity markets by simultaneously considering several hypotheses using a unified econometric framework, specifically a well-established member of the GARCH family of models. While GARCH models are not new to the literature (Zhang et al., 2017; Kang and Yoon, 2020), this model facilitates the estimation of the interplay between mean and volatility effects in commodity futures and equity markets, while accounting for seasonal effects simultaneously. This approach enables a comprehensive consideration of various issues, leading to thorough and methodologically consistent analyses of topics that have previously been contentious.

The main findings of this paper lies in the exploration of diverse outcomes pertaining to the influence of financialisation on the connectedness between equity and twenty-one industrial and agricultural commodity futures markets. This analysis is conducted using two main approaches: first, sub-period analysis and, second, commodity-specific financialisation measures. In the sub-period analysis, which allows us to investigate possible changes over time, we investigate various factors, including (i) volatility persistence, (ii) changes in conditional volatility, (iii) changes in market interdependence, (iv) seasonality, and (v) the Samuelson effect.[4] Using commodity-specific financialisation measure, we explore changes in conditional volatility, conditional correlation, speculative activity and liquidity by using (i) regression and (ii) Granger causality.

Our main findings indicate that higher price volatility is predominantly found in commodities included in benchmark market indices, as opposed to off-index commodities, where such volatility is less pronounced. Conversely, the volatility of equities shows a stronger connectedness with off-index commodities, implying that financialisation may affect both index and off-index commodities.

Second, we observe that financialisation attenuates the seasonal patterns in price volatility for certain index commodities. This shift is attributed to index commodities behaving more like to an equity-like asset class in the wake of financialisation. Furthermore, the larger equity market plays a role in creating volatility spillovers, potentially influencing volatility dynamics within commodity futures markets and diminishing seasonal fluctuations in volatility.

Third, our finding provides empirical support for the notion that financialisation increases the price volatility of nearby contracts more than distant ones, except for metal futures. These results align with Büyükşahin et al. (2008), Phan et al. (2021) and Wadud et al. (2021), indicating similar patterns to the financialisation hypothesis in the crude oil futures market across various maturities. A noteworthy finding in our study is the diminishing Samuelson maturity effect, consistent with Kenourgios and Katevatis (2011), suggesting that commodity futures increasingly taking on characteristics of equity-like assets.

Finally, we show that the Samuelson correlation effect is no longer prevalent in the ma-

[4] This study builds upon the work of Wadud et al. (2021) by investigating the changes in conditional volatility and correlation between equities and multiple commodities, and elucidating how these alterations are impacted by financialisation.

jority of commodities since financialisation. Rather, we find, in some commodities, evidence of an "inverse" Samuelson correlation effect. Varied outcomes are problematic, especially when these outcomes are at odds with generally accepted economic theory. For example, we present findings that are inconsistent with the Samuelson correlation effect (Samuelson, 1965; Schneider and Tavin, 2018).These findings are consistent with Gurrola-Perez and Herrerias (2011) who find the inverse Samuelson effect in volatility, while we have identified the presence in the Samuelson correlation effect. This suggests that Samuelson's original proposition may no longer fully apply in the current financialised context, indicating a shift in market dynamics and the growing influence of speculators.

The relationship between stock market and commodity market in their volatility has been a significant area of study due to the interconnectedness of financial markets and global commodities trade. The literature frequently addresses (i) how price or return volatility in one market spills over into another, (ii) its impact on portfolios, (iii) risk management strategies, and (iv) broader economic outcomes. Filis (2014) and Chang et al. (2013) find a time-varying relationship between stock markets and oil prices. Palanska (2020) show that stock market shocks, particularly from the S&P 500 Index, dominate volatility spillovers to commodities. Furthermore, volatility spillovers between the analysed assets were minimal before the global financial crisis, which significantly increased the connectedness between commodity and stock markets. Berger and Uddin (2016) find that while equity and commodity futures exhibit weak dependence in the short run, there is a stronger long-term correlation between the two asset classes. Kang et al. (2015) find a strong relationship between oil price volatility and stock market returns using a spillover index. Recently, Kang et al. (2024) explored the dynamic relationship between stock market volatility and commodity prices, noting that risk aversion in financial markets can influence commodity price movements.

There is a substantial body of literature examining the effects of financialisation, with a primary focus on oil futures, notably in studies such as Wadud et al. (2021) and Büyükşahin et al. (2008). More recently, Brooks and Teterin (2020) and Fry-McKibbin and McKinnon (2023) have expanded the focus to other commodities, while Gurrola-Perez and Herrerias (2021) and Xu et al. (2021) have explored financial markets. These studies examine the effect of volatility from activities such as (i) arbitrage (Brooks and Teterin, 2020; Xu et al., 2021), (ii) speculative (Phan and Zurbruegg, 2020; Phan et al., 2021; Xu et al., 2021; Gurrola-Perez and Herrerias, 2021), and (iii) liquidity (Phan et al., 2021).

Apart from these studies, existing literature on seasonality primarily addresses agricultural and energy commodities. Several studies incorporate seasonal components in agricultural commodities. For instance, Sørensen (2002); Diop and Sadefo Kamdem (2023); Schneider and Tavin (2024) analyse how seasonality impacts agricultural markets through various modelling approaches. In energy markets, seasonality is often modelled using stochastic factors, forward curves, and time-varying or seasonal risk premia, as explored in works by Mirantes et al. (2012, 2013); Geman and Nguyen (2005); Shao et al. (2015); Chen et al. (2022).

In addition to these studies, Li et al. (2024) examines seasonality in commodity futures returns, adding another dimension to the understanding of periodic market behaviour. Furthermore, research on the seasonality in volatility of commodity prices has been developed by Suenaga and Smith (2011); Back et al. (2013); Ewald and Zou (2021), who propose models to capture seasonal fluctuations in commodity price volatility. These contributions collectively enhance the understanding of seasonality across various commodity sectors, offering insights into both price levels and volatility dynamics.

The Samuelson hypothesis is influenced by levels of stochastic volatility, as seen in energy futures markets (Liu, 2016), and that the maturity effect can occur even in markets without storage, as evidenced in electricity derivatives markets (Jaeck and Lautier, 2016).[5] Other studies, such as those by Phan and Zurbruegg (2020), Phan et al. (2021), and Xu et al. (2021), use microstructural data to demonstrate that price sensitivity to information, as a measure of speculative activity, can explain the variability of the maturity effect in commodity futures and equity markets.

These studies employ different approaches to address seasonality and the Samuelson effect. Brooks and Teterin (2020) adopts a novel approach by interpolating futures prices using a Nelson and Siegel (1987) curve to address noise issues in the volatility-maturity relationship, uncovering a link between carry arbitrage and the Samuelson maturity effect, and showing that this effect persists in markets that are not fully arbitraged. Ho et al. (2023) report the Samuelson effect is more prevalent in agricultural commodity futures (55%) compared to energy (30%), metal, and financial futures contracts (20%), suggesting that mean reversion offers a better explanation for the Samuelson effect. Furthermore, Schneider and Tavin (2024) propose a multi-factor model incorporating a seasonal mean-reversion component into the stochastic volatility dynamics of agricultural commodities, alongside a maturity-dependent damping term to account for the Samuelson effect.

The structure of the remaining discussion is as follows: Section 2 provides an overview of the data, and in Section 3, we outline the methodology used to test our hypotheses. Section 4 and Section 5 present the results from the sub-sample analysis and the use of commodity-specific financialisation measures, accompanied by a discussion in Section **??**. Finally, Section 8 concludes the discussion by summarising the key findings of the study.

2. Data

In this section, we examine two main variables central to our study. They are (1) the extent of speculative activity, which serves as an indicator of financialisation, and (2) the volatility of returns in both (i) commodity futures contracts, and (ii) the S&P500 stock index. Data for these variables, along with other related variables are obtained from three different sources:

[5] Refer to Appendix D of Lautier and Raynaud (2011) and Schneider and Tavin (2024) for empirical literature on the Samuelson effect.

1. Futures prices and trading volumes of selected commodities are sourced from quandl,
2. S&P500 prices are retrieved from Yahoo Finance [https://uk.finance.yahoo.com] and
3. Data on the aggregate traders' position are obtained from the Commitment of Trade (CoT) database of the Commodity Futures Trading Commission (CFTC).

These datasets provide the foundation for our exploration of financialisation and its impact on the connectedness between commodity and equity market.

2.1. Commodity Futures Data

We categorise commodities into two groups,(i) index commodities- those included in the Goldman Sachs Commodity Index (SP-GSCI) and Dow-Jones UBS Commodity Index (DJ-UBSCI), and (ii) off-index commodities- those not included in the indices. We use settlement prices for twenty-one commodity futures traded from January 05, 1993 to December 24, 2019.

Given that multiple contracts are available for each commodity futures at any given time, we concentrate on the most liquid contracts—those closest to maturity—up to the 4$^{\text{th}}$ distant contracts, depending on data availability. The continuous futures series data is obtained from Wiki Quandl (now owned by NASDAQ).[6]

All price series are converted to U.S. dollars. Table 1 presents a detailed description of the commodities, including their sector classifications, ticker symbols on Quandl, the exchanges on which they are traded, their inclusion in the SP-GSCI or DJ-UBSCI indices, and the specific contract months during which they are traded.[7]

Our study predominantly focuses on agricultural commodities, given the stronger presence of seasonality in these markets compared to industrial commodities. However, to investigate how financialisation influences seasonality and the Samuelson effect, and to determine whether these effects differ between index and off-index commodities or across sectors, we have included both agricultural and non-agricultural commodities in our analysis.

2.2. Equity Market Data

The S&P500 index is widely recognised as an aggregate indicator of stock market movement and is frequently utilised as a benchmark for assessing overall equity market performance.[8] In instances where data is missing due to non-trading days, we apply forward filling to maintain data continuity. Our analysis uses return series based on a weekly frequency ending on Tuesdays, aligning with the approach of Adhikari and Putnam (2020) and Wadud

[6]To ensure data validity, we cross-verified the Wiki Quandl dataset with the Energy Information Administration (EIA) dataset by calculating the correlation of commodity futures series. The correlation of price series ranged $0.999 - 1$ and for weekly return series $0.994 - 0.998$. These results are available upon request.

[7]Of the commodity futures studied, fifteen i.e. 71% (5-grains, 4-soft, 2-livestock, 2-energy and 2-metal) are included in the indices, while the remaining six i.e. 29% (4- grains and 2-softs) are off-index commodities.

[8]The S&P500 index is often employed as a proxy for market behaviour in academic research, as demonstrated in studies by Graham et al. (2013), Mensi et al. (2013), Bianchi et al. (2015), and Balcilar et al. (2019), among others.

et al. (2021). This choice of weekly series concluding on Tuesday allows synchronisation with data from the CFTC's Commitment of Traders (CoT) report.[9]

The weekly return series is calculated as the continuously compounded return of futures prices, determined by the difference in the natural logarithms of two successive weekly prices (each Tuesday) for weeks t and $t-1$, represented as follows:

$$r_{i,t} = \ln(P_{i,t}) - \ln(P_{i,t-1}), \quad i = 1, 2, \ldots, 5;$$

where $r_{i,t}$ denotes the weekly price return for the i-th market. We designate 2004 as the starting point for the financialisation period, in accordance with various empirical studies that identify a structural break around this year (see, for example, Büyükşahin et al., 2010; Sanders et al., 2010; Tang and Xiong, 2012; Boons et al., 2012; Hamilton and Wu, 2014). The dataset comprises a total of 1407 observations per return series, with 573 observations prior to and 834 observations during the financialisation period.[10]

Table 1: Commodity Futures Contract with Classification

Ticker	Name	Exchange	Contract Traded Months	Contract Used	Index (S&P GSCI / DJ-UBSCI)	Period
Grains						
W	Chicago Wheat	CME	HKNUZ	1-4	Both	05/01/1993-24/12/2019
KW	KC Wheat	KCBT	HKNUZ	1-4	S&P GSCI	05/01/1993-24/12/2019
C	Corn	CME	HKNUZ	1-4	Both	05/01/1993-24/12/2019
S	Soybeans	CME	FHKNQUX	1-4	Both	05/01/1993-24/12/2019
BO	Soybean Oil	CME	FHKNQUVZ	1-4	DJ-UBSCI	05/01/1993-24/12/2019
O	Oats	CME	HKNUZ	1-3	Neither	05/01/1993-24/12/2019
MW	Minneapolis Wheat	MGEX	HKNUZ	1-4	Neither	01/02/1995-15/05/2018
SM	Soybean Meal	CME	FHKNQUVZ	1-4	Neither	05/01/1993-24/12/2019
RR	Rough Rice	CME	FHKNUX	1-3	Neither	04/10/1994-24/12/2019
Softs						
KC	Coffee	ICE	HKNUZ	1-4	Both	05/01/1993-24/12/2019
SB	Sugar	ICE	HKNUV	1,3,4	Both	05/01/1993-24/12/2019
CC	Cocoa	ICE	HKNUZ	1-4	S&P GSCI	05/01/1993-24/12/2019
CT	Cotton	ICE	HKNVZ	1-4	Both	05/01/1993-24/12/2019
OJ	Orange Juice	ICE	FHKNUX	2-5	Neither	05/01/1993-24/12/2019
LB	Lumber	CME	FHKNUX	1,2	Neither	05/01/1993-24/12/2019
Livestock						
LC	Live Cattle	CME	GJMQVZ	1-4	Both	05/01/1993-24/12/2019
FC	Feeder Cattle	CME	FHJKQUVX	1-4	S&P GSCI	05/01/1993-24/12/2019
Energy						
HO	Heating Oil	NYMEX	FGHJKMNQUVXZ	1-4	Both	05/01/1993-24/12/2019
NG	Natural Gas	NYMEX	FGHJKMNQUVXZ	1-4	Both	05/01/1993-24/12/2019
Metal						
GC	Gold	NYMEX	GJMQVZ	1-4	Both	05/01/1993-24/12/2019
HG	Copper	NYMEX	HKNUZ	1-4	Both	05/01/1993-24/12/2019

Note:
This table presents a total of 21 commodity futures along with their tickers; categorised into 5 sectors namely grains, softs, livestock, energy, and metals. The futures contracts are traded in the Chicago Mercantile Exchange (CME), the Kansas City Board of Trade (KCBT), the Minneapolis Grain Exchange (MGEX), the Intercontinental Exchange (ICE), and the New York Mercantile Exchange (NYMEX). The Contract traded months are provided as code where F-Jan, G-Feb, H-Mar, J-Apr,K- May, M-Jun, N-Jul, Q-Aug, U- Sep, V-Oct, X-Nov, and Z-Dec. The index shows whether the futures contracts are included in either S&P GSCI or DJ-UBSCI index.

[9]The Commitment of Traders (CoT) report, issued by the Commodity Futures Trading Commission (CFTC), provides insight into speculative activity. Data is collected every Tuesday and is publicly released the following Friday.

[10]For the Minneapolis Wheat series, there are 464 observations before the financialisation period and 750 during; for rough rice, there are 482 observations prior to and 834 observations since financialisation.

2.3. Measures of Financialisation

We employ data on open interest, including long positions, short positions, and the total aggregate position, as proxies for the extent of speculative activity—a key indicator in assessing the level of financialisation.[11]

Empirical studies propose several indicators to measure the extent of financialisation or speculative activity.[12] Among these, one of the most commonly used indicators is the Working (1960) 'T' index, defined as the ratio of non-commercial to commercial activity. However, this measure may overestimate speculative activity by including 'non-reporting' traders (Mixon et al., 2018).

Our analysis specifically focuses on non-commercial positions due to financialisation, where 'non-commercial' traders refer to financial investors categorised as money managers, hedge funds, or speculators engaged in the futures market (Gorton and Geert Rouwenhorst, 2006). Consequently, following Hedegaard (2011), we adopt the following specification (1) as our primary proxy to measure the extent of financialisation.[13]

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

For robustness, we also use a ratio of the market share of the long position of speculators over total long positions and speculative pressure as a financialisation measure to check whether the changing measure of financialisation may result in different conclusions in Section 7.

2.4. Measure of Liquidity

Open interest refers to outstanding contracts that remain unexercised through delivery at the end of each trading day. It serves as a widely accepted measure of market liquidity and depth and is often employed to illustrate the stabilizing effect on market volatility (Bessembinder and Seguin, 1993; Ghosh et al., 2012; Martinez and Tse, 2008; Ripple and

[11] Open interest data is classified into three categories prior to 2009—'commercial', 'non-commercial', and 'non-reporting'. Since 2009, it has been further categorized into four classifications: 'traditional commercial', 'commodity swap dealers', 'managed money traders', and 'other non-commercial positions'. As our dataset commences in 1993, predating the availability of the CIT report, we rely on the CoT report. The non-reporting positions are excluded from our analysis as they fall below the reporting regulation threshold.

[12] Examples include speculative pressure, calculated as the difference between non-commercial long and non-commercial short positions relative to the total non-commercial position (Sanders et al., 2010); the ratio of trading volume to open interest in futures contracts (Domanski and Heath, 2007); the proportion of open interest held by non-commercials (Büyükşahin and Robe, 2014); and the net difference between long and short positions held by non-commercials (Brunetti et al., 2016).

[13] We employ this proxy as it provides a relative measure (De Roon et al., 2000) that is closely correlated with speculative pressure (Brunnermeier et al., 2008; Sanders et al., 2010). It represents the net non-commercial position influenced by financialisation. Notably, while we are primarily interested in speculative positions, commercial traders may also hold speculative positions in the publicly available CFTC data (Dewally et al., 2013; Ederington and Lee, 2002), potentially leading to an underestimation of speculative activity. However, due to limitations in publicly available data, this limitation is unavoidable (see also Manera et al., 2016; Bohl et al., 2019).

Moosa, 2009). In this study, we obtain aggregated open interest data from the CFTC Commitment of Traders (CoT) report.[14]

For comparative consistency across variables, we express open interest data in millions. In Section 7, we conduct a robustness check using a detrended series of open interest.

3. Empirical Framework

In this section, we briefly discuss methods used for our empirical study. We use two different approaches i.e. (i) sub-period analysis and (ii) financialisation-specific measures to investigate the impact of financialisation. Section 3.1 explains the model used to estimate time-varying volatility and dynamic conditional correlation to use in both approaches; Section 3.2 shows methods used to analyse the impact of financialisation on volatility dynamics, i.e. (i) volatility persistence, (ii) seasonality in volatility, (iii) the Samuelson maturity effect, and (iv) the Samuelson correlation effect, lead-lag relationship between volatility, correlation, speculative activity, and liquidity.

3.1. Volatility and dynamic conditional correlation

We measure the return and volatility spillovers based on vector autoregressive (VAR) models incorporating seasonal dummies as exogenous variables. We follow Wadud et al. (2021) as non-linear combinations of the GARCH framework with dynamic conditional correlation (DCC) can simultaneously allow us to estimate volatility dynamics and time-varying conditional correlations between equities and commodities. In previous literature, Auer (2014), Lucey and Tully (2006) also use dummy variables to both the mean and the variance equation to capture seasonal effects in returns and volatilities. We define the mean equation as follows:

$$r_t = \mu_t + \Phi r_{t-1} + \Psi d_t + \varepsilon_t \tag{2}$$

$r_t = (r_t^{equity}, r_t^{Com01}, r_t^{Com02}, r_t^{Com03}, r_t^{Com04})'$ is a $k \times 1$ dimensional vector representing returns at time t on $k = 5$ assets used in the model, and in particular the equity index (r_t^{equity}) and upto 4^{th} nearby commodity futures contract.[15] $\mu_t = (\mu_t^{equity}, \mu_t^{Com01}, \mu_t^{Com02}, \mu_t^{Com03}, \mu_t^{Com04})$ is a $k \times 1$ vector of constant terms; Φ is time-invariant $k \times k$ matrices of coefficients with elements $[\Phi]_{ij} = \phi_{ij}$, where $i, j = (equity, Com01, Com02, Com03, Com04)$; Ψ is $k \times 3$ vector of coefficients of seasonal dummy with Northern Hemisphere's seasons; $d_t = (d_t^{winter}, d_t^{summer}, d_t^{fall})'$ is a 3×1 vector where $d_t = 1$ if the season is winter, summer, fall and is 0 otherwise; and $\varepsilon_t = (\varepsilon_t^{equity}, \varepsilon_t^{Com01}, \varepsilon_t^{Com02}, \varepsilon_t^{Com03}, \varepsilon_t^{Com04})$ is a $k \times 1$ vector of the

[14]The CoT report disaggregates total open interest as follows:
$$2(\text{Open Interest}^{All}) = \underbrace{(Long + Short + 2\,Spread)}_{\text{Non-commercial}} + \underbrace{(Long + Short)}_{\text{Commercial}} + \underbrace{(Long + Short)}_{\text{Non-reporting}}.$$

[15]In general, we refer to the nearby commodity futures contract as 1^{st} nearest contract (r_t^{Com01}), the (2^{nd} nearest contract) as (r_t^{Com02}), the 3^{rd} nearest contract or distant futures contract as (r_t^{Com03}) and the most distant futures contract as the 4^{th} nearest contract (r_t^{Com04})

residual returns in r_t.[16]The conditional variances are derived through a first-order univariate GARCH (1,1) process, as follows:[17]

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

where $\omega = (\omega^{equity}, \omega^{Com01}, \omega^{Com02}, \omega^{Com03}, \omega^{Com04})$ is a column vector of constant terms; $[A]_{ij} = \alpha_{ij}$ and $[B]_{ij} = \beta_{ij}$ are $k \times k$ matrices, where $i, j = (equity, Com01, Com02, Com03, Com04)$. The transmission effect is observed through α_{ij} that represents effects of past return shock i.e. short term persistence and β_{ij} shows volatility clustering or long-term persistence/dependency on current conditional variance. In the general GARCH model, conditional variance h_t depends on the squared residuals ε_{t-1}^2 and lagged value h_{t-1}. Similar to Equation (2), seasonal dummy coefficient γ in the variance equation represents whether seasonality affects volatility or not.

The DCC model is estimated using the Quasi-Maximum Likelihood estimator (QMLE) under a multivariate Student t-distribution (see, Harvey et al., 1992; Fiorentini et al., 2003).

3.2. Impact of financialisation

In this section, we outline the methodology used to assess the impact of financialisation on commodity futures and equity markets, focusing on how speculative activity influences both the volatility of these assets and their volatility linkages. We apply both parametric and non-parametric methods to analyse the Samuelson maturity and correlation effects.

To investigate the impact of financialisation, we estimate conditional volatility and conditional correlation using the VAR DCC GARCH model. Before exploring the relationships among the variables, we perform standard diagnostic tests on conditional volatility and conditional correlation, examining both the level and first-difference series. Specifically, we check for outliers using mean, minimum, and maximum values, and test for stationarity using the Augmented Dickey-Fuller (ADF) and Kwiatkowski-Phillips-Schmidt-Shin (KPSS) tests. Our results confirm that all series are first-difference stationary, except for the non-parametric analysis, where we use raw data extracted from the model.[18]

To assess the effects of financialisation, we conduct regression analyses that examine: (i) the impact of financialisation on the volatility of the assets, and (ii) the impact of financialisation on market dependency.

To analyse Samuelson's hypotheses, we employ the two-sample Kolmogorov-Smirnov (KS) test to assess the differences in the distribution of conditional volatility of commodity futures and conditional correlation of equity and commodity futures during pre-financialisation and financialisation period.

[16]We create dummy variables using winter (1 December -28/29 February), Summer (1 June - 31 August), and Fall (1 September - 30 November). In some cases, when there is less than 4 commodity futures series, we keep the contract name based on their actual position from nearby contracts.

[17]We use the lag length of 1 for the VAR-DCC GARCH model on the basis of Schwarz Information Criteria (SIC). SIC of the majority of the commodities are 1.

[18]Detailed results of these diagnostic tests are available from the corresponding author upon request.

Additionally, we apply the Jonckheere-Terpstra (JT) test by Jonckheere (1954) and Terpstra (1952), to evaluate whether the volatility of commodity futures contracts and the correlation between equities and commodity futures contracts are equal, against the alternative hypothesis posits that higher volatility and correlation are observed in nearby futures contract series compared to more distant ones.

Finally, we perform regression and standard Granger causality tests to assess the relationships between financialisation variable ($SI_{i,t}$), liquidity variable ($OI_{i,t}$) and volatility ($\sigma_{ij,t}$) and correlation $\rho_{ij,t}$.

In the following section, we present the empirical results, incorporating a sub-period analysis and a commodity-specific financialisation measure to provide deeper insights.

4. Sub-period analysis

In this section, we examine the findings from the sub-period analysis to assess the impact of financialisation. 4.1 discusses the outcomes from the VAR DCC GARCH model, in particular focusing on the shifts in the volatility persistence before financialisation and during financialisation period. Section 4.2 outlines the results of the estimated conditional volatility, while Section 4.3 discusses the results of the change in conditional correlation attributable to financialisation. Section 4.4 explores the alterations in seasonal patterns, and Section 4.5 addresses the modifications to the Samuelson hypothesis, particularly in terms of volatility and correlation between commodity and equity markets.

4.1. Volatility persistence

In this section, we present the initial key findings of the paper by focusing on volatility patterns generated by the GARCH model. The results of the mean estimation, while available upon request, are not reported here.[19] Parameter α_{ij} in (3) is statistically significant for all futures contracts, signifying short-term volatility persistence in corn, oats, sugar, live cattle, feeder cattle, and gold before financialisation. For other commodities, α_{ij} is not statistically significant across all contract maturities, suggesting the absence of short-term volatility persistence in both periods. These results are largely consistent with ARCH-Lagrange Multiplier (LM) test findings.

Regarding GARCH effect, $\beta_{i,j}$ in Equation (3) is statistically significant for the majority of commodity futures contracts, indicating that these markets' volatilities are sensitive to their own past conditional volatilities. Notably, soybeans and coffee were exceptions, displaying no GARCH effect before financialisation, but they exhibited long-term persistence during the financialisation period.

[19] Overall, VAR analysis reveals that, before financialisation, S&P500 index exhibits own-lag effects and mean-reverting behaviour, aligning with Vo (2011). This pattern shifted during financialisation. Cocoa was the only market displaying equity-to-commodity spillover before financialisation, while post-financialisation, spillovers occurred in oats, coffee, live cattle, feeder cattle, natural gas, and gold markets.

The joint significance of the parameter shows both short-term and long-term persistence of shocks in dynamic conditional correlation, which we find are significant for all commodities except Feeder Cattle and Live Cattle, reflecting time-varying conditional correlation. Furthermore, in all instances, we observe evidence of long-run persistence of volatility spillover between equity and commodities.

These significant findings across various factors, including the ARCH and GARCH effects, provide insight into price volatility patterns in commodity markets. We now shift our focus to understanding the extent of volatility changes due to financialisation, elaborating on these results in the following section.

4.2. Conditional volatility

Figures 1 and 2 illustrate changes in the mean of conditional volatility for index and off-index commodities respectively, focusing on nearby month contract for brevity. For the majority of index commodities, we observe an increase in conditional volatility since the onset of financialisation, with the exception of two commodities in the softs and energy sectors.

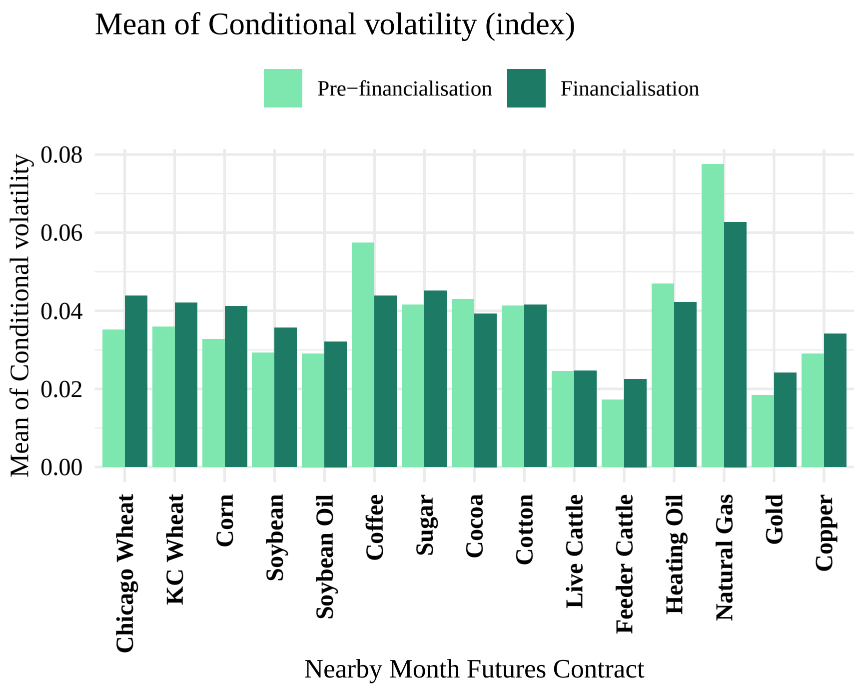

Figure 1: Mean of the estimated volatility of the nearby month index commodities

In the case of energy commodities, i.e. heating oil and natural gas, we find that price volatility has decreased since 2004. Geman and Ohana (2009) find a negative correlation between price volatility and inventory levels, suggesting that fluctuations in natural gas prices are not affected by long-term volatility. Instead, natural gas inventories are more closely linked to front-month price volatility rather than adjusted spread volatility. Therefore, we anticipate that short-term volatility patterns, such as intraseasonal variations, will be more

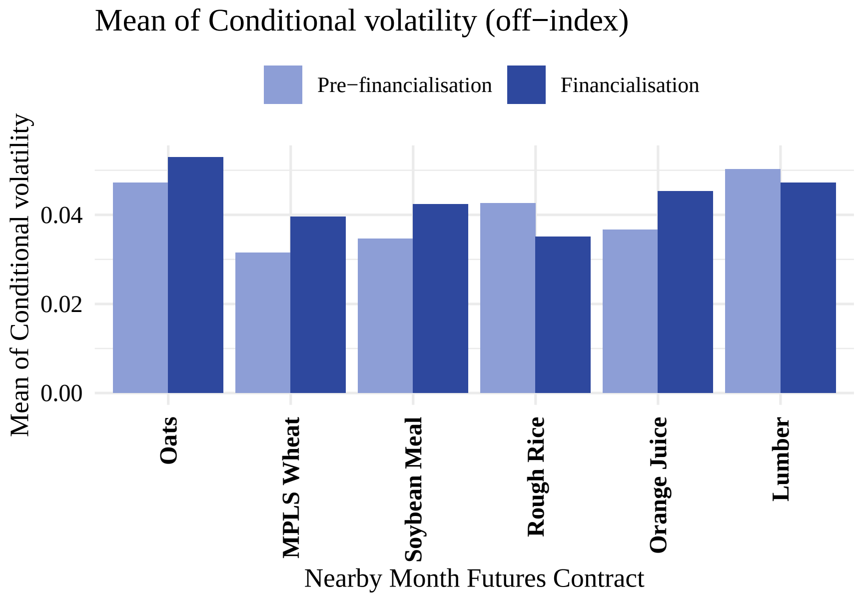

Figure 2: Mean of the estimated volatility of the nearby month off-index commodities

prominent in energy markets. A more closure insight into the seasonal pattern is discussed later in Section 4.4.

The coffee and cocoa markets have also experienced reduced volatility since financialisation. Dahl et al. (2020) note that cocoa typically exhibits the highest volatility during periods of volatility spillovers. This decrease in volatility aligns with the conventional notion that increased speculative activity tends to dampen commodity price volatility.

Unlike index commodities, only rough rice and lumber have seen a decline in volatility since financialisation. These commodities are characterised by lower trading frequency, which likely prevents an increase in volatility. On the contrary, 67% of off-index commodities have experienced heightened volatility since financialisation, consistent with the trend observed in index commodities.

In summary, the rise in volatility since financialisation is more prominent in index commodities compared to off-index commodities, although this is generally observed in both- a key contribution of this study.

4.3. Market interdependence

The correlations between assets have exhibited significant changes over the past two decades. Figures 3 and 4 provide an overview of these shifts, focusing on the mean conditional correlations between equity and commodities. Figure 3 highlights that the mean of the conditional correlation between equity and index commodity futures have generally increased, with the exception of natural gas.

These shifts in correlation are particularly pronounced in index commodities, where we see a clear increase, while off-index commodities display a similar but less significant trend. This evolution in correlation dynamics underscores the growing interconnectedness between equity and commodity markets, which has been widely attributed to the process of

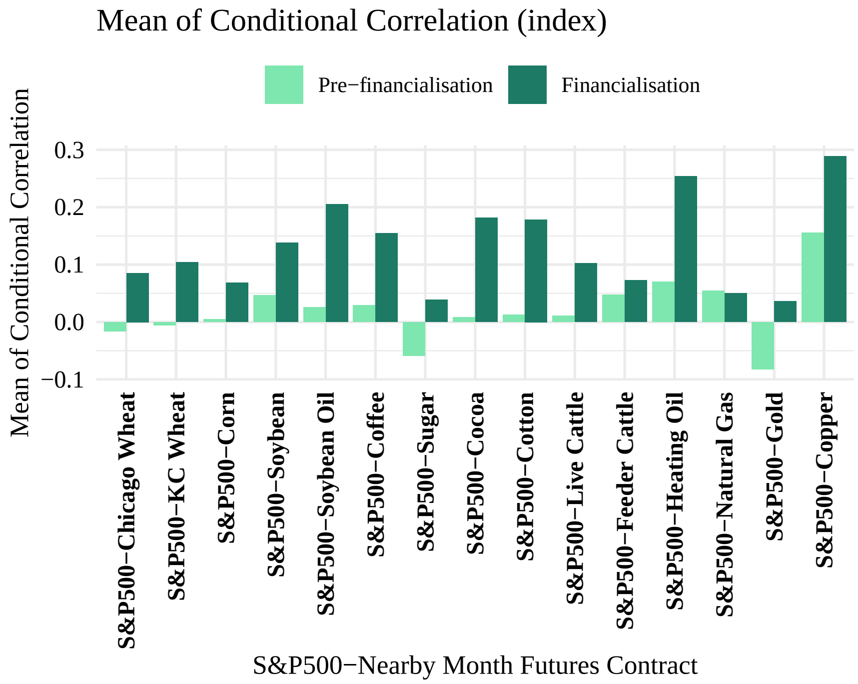

Figure 3: Mean of the estimated correlation between the equity and the nearby month index commodities

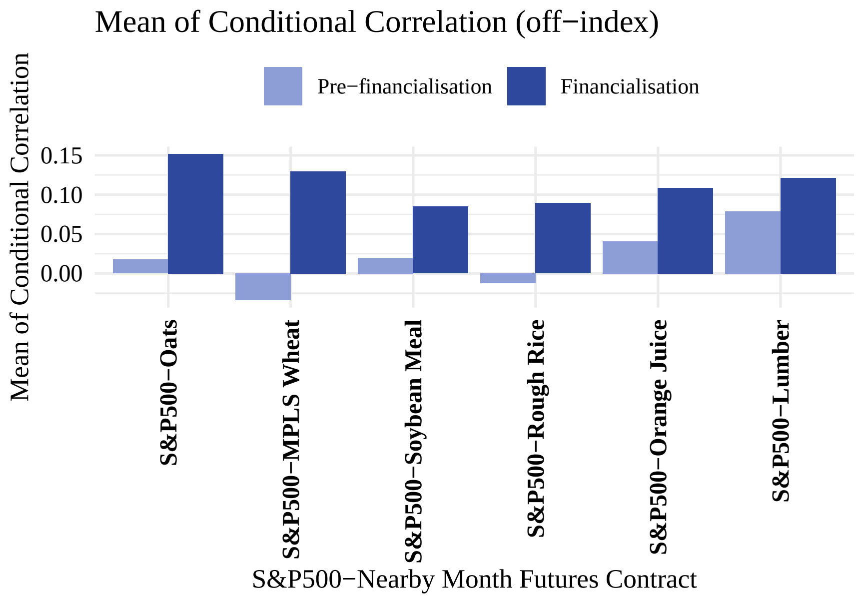

Figure 4: Mean of the estimated correlation between the equity and the nearby month off-index commodities

financialisation. This finding aligns with existing literature, such as the work of Tang (2012) and Silvennoinen and Thorp (2013), who suggest that financialisation has increased co-movements between financial and commodity markets. The significant changes in conditional correlations represent a key contribution of this study, offering further insight into the impact of financialisation on market linkages.

4.4. Seasonality

Our analysis using the Dynamic Conditional Correlation (DCC) model indicates a lower level of price volatility. However, when we apply the DCC model without including lag or seasonality components, are estimates are closer to those analysed in the summary statistics.[20] The lower level of volatility using the DCC model can be attributed to the inclusion of seasonality and the VAR component. This highlights the importance of considering the seasonality component when forecasting volatility, as models failing to account for seasonal fluctuation from futures prices, may yield erroneous forecasts by overstating the actual volatility, potentially leading to spurious prediction in estimating risk and return, a concern also noted by Schneider and Tavin (2024) in their discussion of seasonal mean-reversion.

Seasonality in commodity prices reflects fundamental supply-demand cycles, such as agricultural harvests, heating demand for energy commodities, and investment cycles for precious metals. These cycles are shaped by predictable factors, such as climate conditions and consumption patterns. Inventory levels are also a critical determinant of price volatility, particularly in agricultural and energy markets. Low inventory levels heighten sensitivity to external shocks, such as unexpected weather events or geopolitical disruptions.

Table 2 presents the seasonal effects on the variances of commodity futures contracts. Our findings reveal that seasonality is more pronounced in the mean returns than in volatility, both before and during the financialisation period. This is consistent with Schneider and Tavin (2024) who found seasonal patterns in agricultural markets driven by inventory levels and harvest cycles. Our hypothesis is supported for mean returns in five commodities: Chicago wheat, KC wheat, Minneapolis wheat, rough rice, and orange juice. This indicates that 50% of off-index and only 13.33% of index commodities exhibit seasonality in mean return to diminish since financialisation. Interestingly, we observe a higher prevalence of seasonal patterns in mean returns since the financialisation, with 61.91% commodities showing strong seasonality. Among these commodities, the majority of the commodities show seasonal patterns, primarily in winter and fall. For instance, soybean meal and corn exhibit seasonal patterns exclusively during the summer since financialisation, a finding consistent with Goodwin and Schnepf (2000), who reported heightened price volatility for corn during the summer harvest.

Table 2: Seasonality in variance

	pre-financialisation				***financialisation***			
	Heating oil 4	Natural gas 2	Natural gas 2	Gold 3	Heating oil 4	Natural gas 2	Natural gas 2	Gold 3
Winter	0.0000000	0.0000000	0.0000000	0.0000135**	0.0000000	0.0000000	0.0000000	0.0000000
se_w	(9.8e-06)	(1.3e-06)	(1.3e-06)	(3.44e-05)	(2e-07)	(1.3e-06)	(1.3e-06)	(4e-06)
Summer	0.0000022	0.0001624	0.0000000	0.0000230	0.0000000	0.0001624	0.0000000	0.0000000
se_s	(7.4e-06)	(1.32e-05)	(1.32e-05)	(4.07e-05)	(6.4e-06)	(1.32e-05)	(1.32e-05)	(1.38e-05)
Fall	0.0000072**	0.0003451**	0.0001455*	0.0000000	0.0000000	0.0003451**	0.0001455*	0.0000000
se_f	(1.74e-05)	(1.1e-06)	(1.1e-06)	(2.15e-05)	(2.3e-06)	(1.1e-06)	(1.1e-06)	(1.92e-05)

Note:
This table reports the seasonality in the variance of heating oil, natural gas, and gold that is gathered from the VAR DCC GARCH model for both pre-financialisation and financialisation periods. Standard errors are in parentheses.
* ***,** and * denote statistical significance at 1%, 5%, and 10% level.

[20] These results are available on request.

Seasonal price variation is also observed in natural gas during fall, similar to heating oil. This is intuitive, as both natural gas and heating oil are often used as a substitute for heating in colder months. Křehlík and Baruník (2017) attribute seasonal patterns in heating oil to demand factors, while Hevia et al. (2018) report similar patterns in natural gas, which exhibits a more pronounced seasonality. This heightened seasonality could be due to the higher costs associated with refining, storage, and transportation of natural gas compared to heating oil. Geman and Ohana (2009) also note increased price volatility in natural gas during the winter.[21] Seasonal investment and consumption patterns influence precious metal prices. In precious metals, our results align with Lucey and Tully (2006), who reported seasonal price variations in gold, indicating a broader applicability of seasonality across commodity types.

Financialisation appears to weaken the seasonal patterns in volatility across most cases where such seasonality exists. This reduction in seasonal variation aligns with the findings of Hevia et al. (2018), who also observe a decline in seasonal variation over time. They attribute this reduction to changes in demand composition, including decreased residential use, increased exports, and the growing use of natural gas as a non-seasonal transportation fuel.[22] Additionally, Baur and McDermott (2010) suggest that commodity loses their traditional real characteristics and aligns them more closely with financial assets, thereby reducing the impact of underlying demand and supply seasonality on price volatility. Meanwhile, Haglund (2014) attributes the change in the fluctuation of seasonal patterns to the influence of financialisation. The exception to this trend is sugar, where seasonal volatility has persisted, perhaps reflecting unique market conditions or production cycles.

The pronounced seasonal pattern in the variance of a few commodities since financialisation could be because commodities that were not traded earlier, are traded now with different maturities. Due to very low and stable trading volume before the financialisation, seasonality is not observed in either mean return or volatility. However, since financialisation, increased commodity investing may have enhanced seasonal patterns, likely driven by fluctuations in trading volume due to factors such as day-of-the-week effects, weekends, holidays, seasonal harvesting period, climate conditions.[23] Collectively, these factors can translate to regular seasonal patterns in both mean returns and price volatility. This increased trading activity may amplify existing seasonal signals in both mean returns and price volatility, a trend also observed in the S&P500's seasonal connectedness with heating oil, potentially reflecting cross-asset spillovers since financialisation.

Our findings support our hypothesis on the diminishing seasonality in volatility for index commodities, marking the second finding of this study. This outcome aligns with prior research, which suggests that financialisation impacts index commodities more substantially

[21] They consider the winter season from November till March where we include November in the fall season; hence, we find seasonality in fall.

[22] This decrease is also reported by EIA (2017).

[23] Summary description of trading volume to explain such results are available from the corresponding author.

than off-index commodities.

Beyond seasonal fluctuations, another prominent volatility pattern in commodity markets is the time-to-maturity or Samuelson Volatility effect, which is examined in the following section.

4.5. Samuelson hypothesis

We report the appearance of the Samuelson hypothesis broadly by categorising them into two distinct effects: (i) the Samuelson volatility effect and (ii) the Samuelson correlation effect.

It is difficult to distinguish between seasonal patterns and time-to-maturity patterns as the maturity effect is a linear trend variable for a single contract and the linear seasonality can not be differentiated from the maturity effect Goodwin and Schnepf (2000, p. 756). To address this issue in our analysis, we use visual inspection, as well as parametric and non-parametric method, to better capture these patterns.[24]

4.5.1. Samuelson volatility effect

We examine the potential inverse relationship between volatility and the time-to-maturity of the contracts by using conditional volatility estimates derived from our model, in line with the approach taken by Lautier and Raynaud (2011). We analyse the distribution of conditional volatility across various maturities, providing insights into the interplay of financialisation, market structure, and traditional economic fundamentals. For illustrative purposes, Figure 5 presents the distribution of the conditional volatility of the KC wheat for both the pre-financialisation and financialisation period. In most cases, we observe a rightward shift in the distribution during the financialisation period, as demonstrated by KC wheat, indicating an increase in conditional volatility for most commodities, consistent with the findings of Tang (2012), who attribute heightened volatility to speculative activity and increased financial market participation.

During the pre-financialisation period, we observe that the mean of conditional volatility of front-month contracts exceeds that of more distant contract, suggesting that conditional volatility tends to decrease with increasing maturity. This finding confirms the *Samuelson maturity/volatility effect*, which predicts a decline in volatility as the time to maturity increases. This relationship is evident across all commodities except gold, consistent with Ho et al. (2023), who report an absence of the maturity effect for metals. In the case of gold, increased volatility since financialisation appears partly driven by seasonal factors, combined with the influence of macroeconomic variables such as inflation and geopolitical risks. Seasonal dynamics, as mentioned in the may still manifest in specific metals, especially under financialised trading conditions.

[24] We have opted not to incorporate time-to-maturity dummies in our model to avoid introducing additional parameters and thereby increasing the model's complexity.

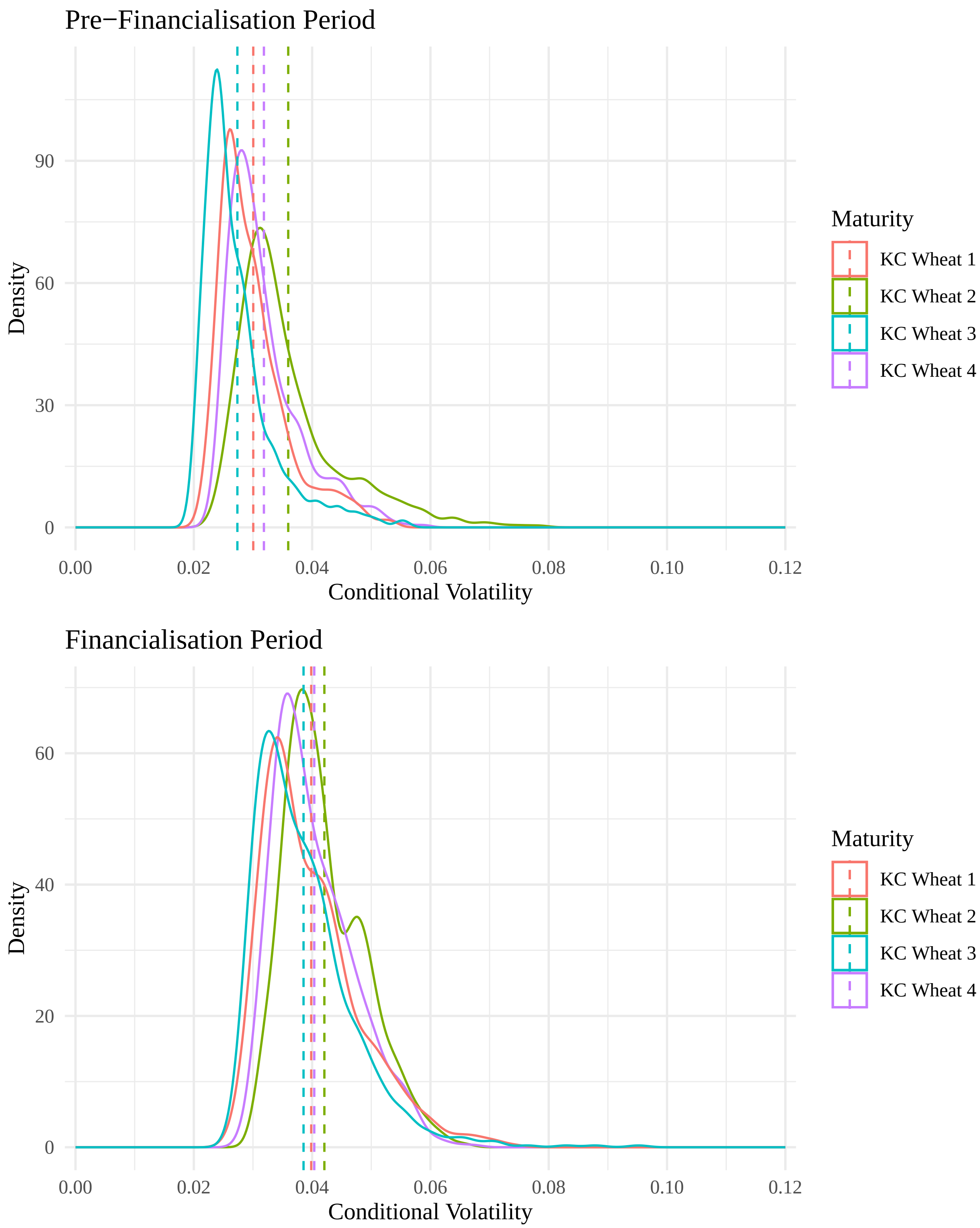

Figure 5: Distribution of conditional volatility for KC Wheat

Although conditional volatility has generally risen across commodities since financialisation, certain futures markets exhibit a smaller increase in mean of the volatility for the front-month contract compared to distant contracts. In these markets, the Samuelson effect remains, albeit with reduced magnitude. For instance, in the cotton market, the increase in conditional volatility of the nearest contract ($\Delta 1^{\text{st}} CT$) is modest (0.003) compared to that of the most distant contract ($\Delta 4^{\text{th}} CT$), which increases more substantially (0.0045) since financialisation.[25] This diminishing Samuelson effects are observed in the futures market for rough rice, coffee, cocoa, lumber, feeder cattle, heating oil, and natural gas. This weakening of the Samuelson effect aligns with the findings of Schneider et al. (2024), who attribute such deviations to liquidity dynamics and stochastic convenience yields in financialised markets. Increased trading activity and speculative flows amplify the volatility of distant contracts, reducing the relative difference between nearby and longer-dated futures, as further discussed in Section 5.1.1.

We assess differences in volatility distributions between pre-financialisation and financialisation periods using non-parametric Kolmogorov-Smirnov (KS) tests. The null hypothesis of this two-sample KS test is that there is no difference between the distributions of time-varying conditional volatility for futures contracts across the two periods. The results confirms significant differences in the distribution of conditional volatility, as estimated from the DCC framework, across these periods for most commodities, with the exception of certain metals.

Further, we apply the JT test to evaluate the persistence of the Samuelson maturity effect. [26] Testing the Samuelson hypothesis necessitates evaluating the order of volatility among contracts with varying expiry dates. Unlike earlier studies (e.g. Duong and Kalev, 2008; Jaeck and Lautier, 2016), our model incorporates weekly conditional volatility estimates from a VARX-DCC-GARCH framework, accounting for intra-seasonal patterns. This allows us to determine whether the Samuelson volatility effect holds even after accounting for seasonality.

An overview of the Samuelson volatility effect by using the JT test is presented in Table 3. Before financialisation, the null hypothesis is rejected for all commodities except gold, indicating higher volatility in nearby month futures contracts compared to distant contracts. This evidence confirms the persistence of the *Samuelson maturity effect* in most commodities before financialisation. However, during financialisation, the effect is absent for metals, reflecting their reduced dependence on seasonal supply dynamics and greater sensitivity to macroeconomic variables. The absence of maturity effect is widely documented in the literature (among others, Fama and French, 1988; Duong and Kalev, 2006). This deviation could be attributed to the fact that metal commodities are less dependent on seasonal supply variations and have greater sensitivity to macroeconomic factors like inflation, interest rates, political stability, and others. Studies like Ng and Pirrong (1994) suggest that fundamentals

[25] Here, ($\Delta 1^{\text{st}} CT$ denotes the difference in mean of conditional volatility of nearby contracts during financialisation and before financialisation period.

[26] D-statistics for both KS and JT test for the volatility of index and off-index commodities can be found in Tables C.11-C.14 in online Appendix C.

drive metal price dynamics, while Kenourgios and Katevatis (2011) link diminished maturity effects to liquidity and trading activity. Consequently, the Samuelson effect is notably absent in metal commodities.

Table 3: Overview of Samuelson volatility effect on the volatility of commodity futures

Samuelson holds		*Samuelson doesn't hold*		*Diminishing effect*
pre-financialisation	**financialisation**	**pre-financialisation**	**financialisation**	**financialisation**
Index				
Grains: Chicago wheat, Kansas wheat, corn, soybean, soybean oil	Grains: Chicago wheat, Kansas wheat, corn, soybeans, soybean oil	Metal: Gold	Metal: Gold, copper	Softs: Coffee, cocoa, cotton
Softs: Coffee, sugar, cocoa, cotton	Softs: Coffee, sugar, cocoa, cotton			Livestock: Feeder cattle
Livestock: Live cattle, Feeder cattle	Livestock: Live cattle, Feeder cattle			Energy: Heating oil, natural gas
Energy: Heating oil, natural gas	Energy: Heating oil, natural gas			
Metal: Copper				
Off-index				
Grains:Minneapolis wheat, soybean meal, oats, rough rice	Grains:Minneapolis wheat, soybean meal, oats, rough rice			Grains: Rough rice
Softs: Orange juice, lumber	Softs: Orange juice, lumber			Softs: Lumber

Note:
This table presents the overview of the Samuelson maturity effect before and during financialisation period. The commodities are categoried based on index and sector. The first two column shows the commodities that show the Samuelson maturity effect. The third and fourth columns show the commodities for which the Samuelson maturity effect does not hold. The fifth column shows the commodities for which there is a diminishing Samuelson maturity effect. The results are gathered from Jonckheere-Terpstra (JT) test for the estimated volatility of commodity futures. There is the existence of the Samuelson maturity effect when the null hypothesis of equal volatilities is rejected.

Our findings indicate the Samuelson maturity effect holds across all off-index commodities, whereas it manifests in 87% of index commodities. This supports the hypothesis that financialisation exerts a more pronounced influence on index commodities, potentially diminishing or eliminating the Samuelson maturity effect through speculative flows and benchmarking effects - a result we identify as a third key finding of this study. These changes in market structure align with the theoretical models of Basak and Pavlova (2016), who emphasise the role of institutional investors in aligning commodity prices with broader financial markets.

Our findings contribute to the growing literature on the impact of financialisation on commodity markets, particularly its influence on the Samuelson effect and volatility patterns. Consistent with studies such as Gorton and Geert Rouwenhorst (2006) and Tang (2012), we demonstrate that financialisation alters traditional price dynamics by introducing speculative behavior and increasing market liquidity. Given the observed changes in volatility patterns attributable to financialisation, correlations among commodity futures contracts may also be affected, and we explore this impact in the following section.

4.5.2. Samuelson correlation effect

This subsection evaluates the Samuelson correlation effect in commodity futures markets and investigates how financialisation has influenced the volatility dynamics between equity and commodities. According to the Samuelson hypothesis, correlations between nearby and next-nearby futures contracts are expected to be higher than those between nearby and distant contracts. This effect, rooted in economic fundamentals, reflects the diminishing impact of shared market information as the time-to-maturity of contracts increases.

Our analysis begins by examining changes in the mean of conditional correlations among commodity futures across various maturities. [27] Most commodities exhibit the Samuelson correlation effect, as demonstrated in markets such as Chicago wheat. For instance, the mean of correlation between nearby and next nearby contract is 0.912 (pre) and 0.984 (during), while the mean of correlation between nearby and most distant futures is 0.776 (pre) and 0.926 (during), showing lower values (0.136-pre, 0.058-during). This pattern aligns with the *Samuelson correlation effect*, indicating a diminishing correlation with increasing maturity. These findings are consistent with Schneider and Tavin (2018) and Wadud et al. (2021).

However, since financialisation, this effect has not been consistently observed across all commodities. For some, the correlation between nearby and distant contracts has increased, reflecting the influence of financialisation on traditional market dynamics. This shift aligns with the theoretical advancements of Basak and Pavlova (2016), who argue that institutional benchmarking and speculative flows increase systemic correlations. Hence, this may weaken the Samuelson effect.

Next, we examine the interplay between equity and commodity markets by inspecting the distribution of conditional correlations before and during financialisation. Figure 6 illustrates the distribution of equity-Chicago wheat correlations across maturities. A rightward shift is evident, signifying stronger connectedness between equity and commodity futures markets post-financialisation. Notably, natural gas exhibits an exception, with correlations remaining comparatively stable.

The Kolmogorov-Smirnov (KS) test statistically confirms a significant change in the distribution of equity-commodity correlations across the two periods.

We also assess whether the correlation between equity and commodities across different maturities confirms to the Samuelson correlation effect. Contrary to expectations, Wadud et al. (2021) identify an 'inverse' Samuelson correlation effect in the equity-crude oil futures market, wherein the correlation increases as contracts move further away from the front-month contract, especially since financialisation.

Table 4 summarises the presence of the Samuelson correlation effect across commodities and sectors. Before financialisation, the effect holds for most off-index commodities (e.g., rough rice, soybean meal, oats) and certain index commodities (e.g., KC wheat, soybeans, heating oil).[28] During financialisation, this phenomenon is only noticeable in the cases of

[27] These results are available on request from the corresponding author.

[28] D-statistics for both KS and JT test for the correlation between equity and index and off-index com-

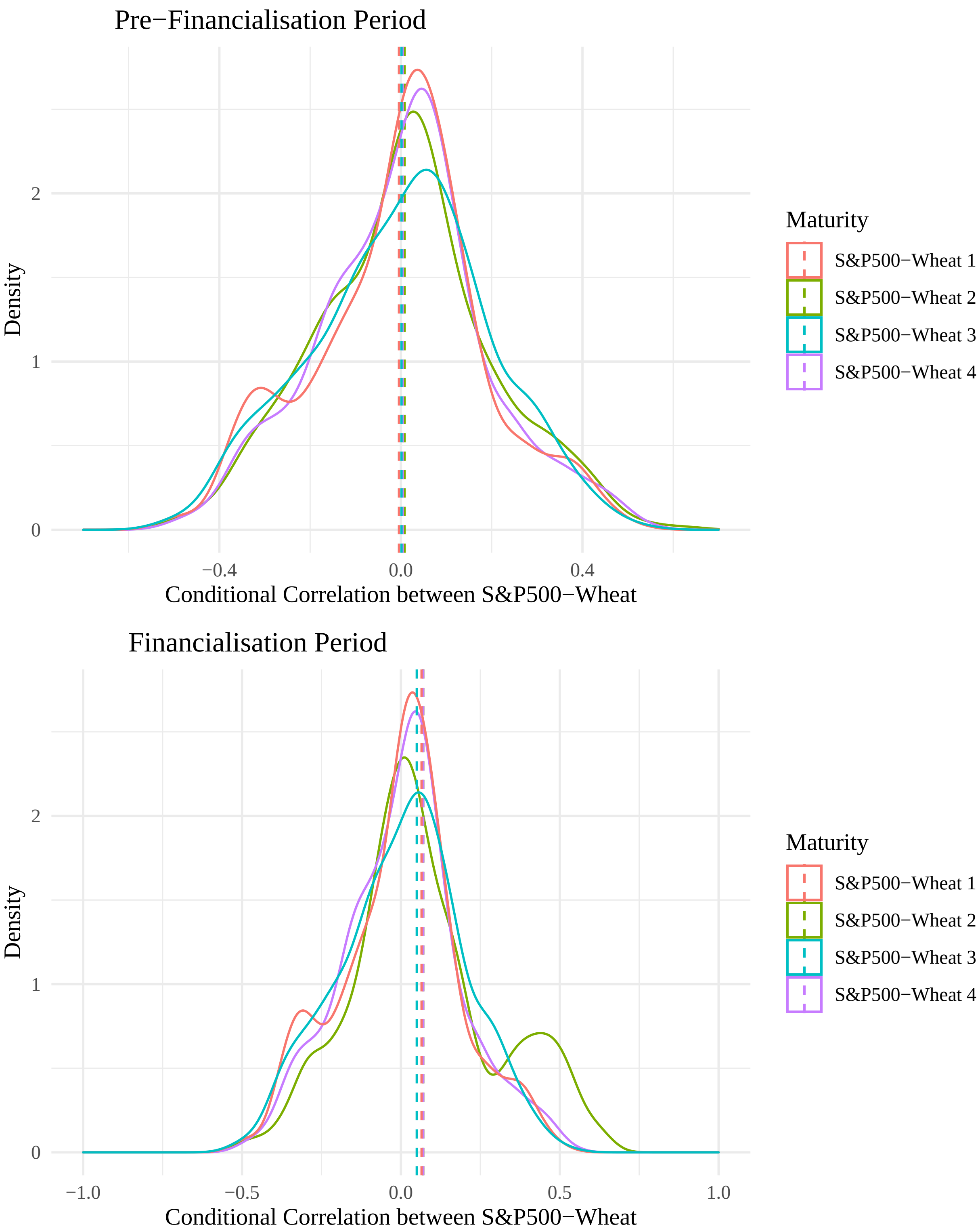

Figure 6: Distribution of conditional correlation between equity and Chicago wheat futures

Table 4: Overview of Samuelson correction effect on the equity-commodity

Samuelson holds		*Samuelson doesn't hold*		*Inverse Samuelson effect*
pre-financialisation	**financialisation**	**pre-financialisation**	**financialisation**	**financialisation**
Index				
Grains: Kansas wheat, soybeans	Grains: Chicago wheat, Kansas wheat	Grains: Corn, soybean oil	Grains: Corn, soybeans, soybean oil	Grains: Soybeans
Livestock: Live cattle, feeder cattle		Softs: Coffee, sugar, cocoa, cotton	Softs: Coffee, sugar, cocoa, cotton	Softs: Coffee, sugar, cocoa, cotton
Energy: Heating oil		Energy: Natural gas	Energy: Heating oil, Natural gas	Livestock: Live cattle, feeder cattle
		Metal: Gold, copper	Metal: Gold, copper	Energy: Natural gas
Off-index				
Grains: Soybean meal, rough rice, oats	Grains: Minneapolis wheat	Grains: Minneapolis wheat	Grains: Soybean meal, oats, rough rice	Grains: Minneapolis wheat
Softs: Orange juice, lumber			Softs: Orange juice, lumber	Softs: Orange juice, lumber

Note:
This table presents the overview of the Samuelson correlation effect in equity-commodities before and during the financialisation period. The commodities are categorised based on index and sector. The first two columns show the commodities that show the Samuelson maturity effect. The third and fourth columns show the commodities for which the Samuelson maturity effect does not hold. The fifth column shows the commodities for which there is a diminishing Samuelson maturity effect. The results are gathered from the Jonckheere-Terpstra (JT) test for the estimated volatility of commodity futures. There is the existence of Samuelson's maturity effect when the null hypothesis of equal volatilities is rejected.

Chicago wheat, KC wheat, and Minneapolis wheat. Financialisation increases correlations across maturity, but this increase is not uniform, likely due to the varying investment patterns of financial investors. Notably, the Samuelson correlation effect disappears in nine commodities (soybeans, soybean meal, rough rice, oats, orange juice, lumber, live cattle, feeder cattle, and heating oil). This leads to the fourth finding of this paper, where we identify an *inverse Samuelson correlation effect* in 11 commodities, wherein the conditional correlation between equity and commodity increases as the contract maturity moves further from the underlying contract. This observation echoes the findings of Gurrola-Perez and Herrerias (2011) and Gurrola-Perez and Herrerias (2021) in the context of interest rate futures, indicating investors are increasingly favouring longer-horizon contracts since the financialisation.

The Samuelson correlation effect and its variations reflect deeper economic mechanisms influenced by financialisation:

In summary, significant shifts in volatility and correlation patterns have been observed since financialisation. Yet, attributing these changes solely to financialisation, as opposed to liquidity dynamics, remains uncertain without considering further examination of speculative and liquidity-related variables. In the next section, we address this issue further using regression and Granger causality analyses.

modities can be found in Tables C.15-C.18 of the online Appendix C.

5. Commodity-specific financialisation measures analysis

This section explores the impact of financialisation on commodity-specific volatility and equity-commodity correlations through speculative activity and liquidity measures, such as speculative index and open interest. By employing regression analysis and Granger causality tests, we aim to uncover the causal mechanisms driving volatility and correlations, shedding light on the evolving role of commodities as diversification tools during the financialisation period.

5.1. Regression analysis

We perform a regression analysis to examine the relationships between conditional volatility, speculative activity, and liquidity measures. This approach provides insights into the economic mechanisms underpinning the observed dynamics, such as risk sharing, market efficiency, and the influence of financialisation on volatility.

5.1.1. Connectedness between conditional volatility, speculative activity and liquidity

The regression results reveal a nuanced relationship between speculative activity, liquidity, and commodity volatility. The coefficient (ζ_1) of the speculation index is both positively and significantly associated with the volatility of soybean oil and cocoa, indicating that fluctuations in speculative activity exert a notable impact on these commodity markets. Additionally, we observe partial effects of speculative activity on the volatility of corn, lumber, sugar, and feeder cattle, particularly within one or two contract maturities. Corn stands out as having a consistent positive correlation with speculative activity, aligning withEtienne et al. (2018), who find that positive shocks in non-commercial net positions impact corn price variability. They also suggest that non-commercial positions generally follow the hedging demands of commercial traders—demands which are typically driven by fundamental market conditions; the significant influence of speculative activities likely reflects shifts in underlying supply and demand dynamics.

Table 5: Overview of the impact of speculative activity and liquidity on the volatility of commodity futures

Type	pre-financialisation	financialisation	pre-financialisation	financialisation
Index	13% (+)ve	13% mixed	46% mixed (partial)	13% (-)ve (partial).
Off-Index	No impact	16% (+)ve	33% (-)ve (partial)	10% (-)ve.

Note:
The table represents a brief summary of the results using regression: $\sigma_{ij,t} = \zeta_0 + \zeta_1 SI_i + \zeta_2 OI_i + e_{ij,t}$; where ζ_0,ζ_1,ζ_2, $\sigma_{ij,t}$, and $e_{j,t}$ is a constant, coefficient of speculative activity, coefficients of liquidity, conditional volatility of either equity or commodities where j is various maturity contracts of a commodity in 4×1 vector form, and standardised error term respectively. Speculation index is measured by $\frac{Non\text{-}commercial\ Long\ Position - Non\text{-}commercial\ Short\ Position}{Total\ Open\ Interest}$ following Hedegaard (2011) and liquidity is measured by aggregate open interest. 'Partial' represents a significant impact on a few contracts with different maturities of a particular commodity.

Speculative activity during financialisation further increases volatility in coffee and lumber while reducing it for gold. The differential impacts align with Manera et al. (2013), who note that long-term speculation often exhibits commodity-specific volatility effects. For gold, the reduction in volatility aligns with its use as a safe-haven asset during financial stress.

During the financialisation period, speculative activity tends to increase volatility in coffee and lumber, while reducing it in gold. We also observe some partial effects of speculation impacting positively (negatively) the volatility of KC wheat, corn, and soybeans (rough rice, feeder cattle). Haase and Huss (2018) reports an opposite finding regarding the impact of speculation on KC wheat, possibly due to differences in the measure of speculation used or the influence of herding behaviour, where speculators gradually affect the conditional volatility of KC wheat positively. The differential impacts align with Manera et al. (2013) who suggest that long-term speculation has either negative (opposite to ours) or insignificant effects on volatility. For gold, the reduction in volatility aligns with its use as a safe-haven asset during financial stress.

Overall, 13% of index commodities exhibit a positive relationship with speculative activity before financialisation, with mixed effects observed in 13% of index commodities post-financialisation. Interestingly, speculative activity barely affects off-index commodities before financialisation, but it positively impacts the volatility of 16% off-index commodities. This finding is particularly noteworthy, as prior literature has predominantly focused on the impact of financialisation on index commodities and our experimental approach appears to be better suited to address this question than earlier studies.

Turning to the impact of change in open interest (ζ_2) on the change in the volatility commodity market, we observe both significant and insignificant correlation. However, with the exception of orange juice, most results are insignificant. The negative relationship between orange juice volatility and open interest aligns with findings by Watanabe (2001). Overall, our results suggest that liquidity has not played a significant role in influencing commodity futures volatility since the advent of financialisation.

5.1.2. Connectedness between conditional correlation and speculative activity and liquidity

Before financialisation, we observe no significant correlation between speculative activity and changes in the correlation of equity-commodity futures, except for coffee and natural gas.[29] Speculative activity positively impacts the conditional correlation between equity and coffee as well as between equity and natural gas. However, with the exception of KC wheat, no significant impact is found on the correlation between equity and other commodities. Interestingly, an increase in speculative activity decreases the correlation between equity and KC wheat futures, as indicated by the negative coefficients ($\eta_1^{KW} = -0.22, -.20, -.16, -.14$).

When examining the relationship between conditional correlation and open interest, we find that before financialisation open interest negatively affects equity-sugar and equity-gold, and the impacts decreases ($\eta_2^S B = -0.46, -0.42, -0.34$ and $\eta_2^G C = -0.71, -0.65, -0.64,$

[29]Some of these regressions show peculiar results due to low trading volume and open interest during that period, resulting in poor R^2 and adjusted-R^2 values.

Table 6: Overview of the impact of speculative activity and liquidity on the correlation between the equity and commodities

Type	pre-financialisation	financialisation	pre-financialisation	financialisation
Index	13% (+)ve	13% mixed	46% mixed (partial)	13% (-)ve (partial)
Off-Index	No impact	16% (+)ve	33% (-)ve (partial)	10% (-)ve.

Note:
The table represents a brief summary of the results using regression: $\rho_{ij,t} = \eta_0 + \eta_1 SI_i + \eta_2 OI_i + v_{ij,t}$; where η_0,η_1,η_2, $\rho_{ij,t}$, and $v_{ij,t}$ is a constant, coefficient of speculative activity, coefficients of liquidity, conditional volatility of either equity or commodities where j is various maturity contract of commodity in 4×1 vector form, and standardised error term respectively. Speculation index is measured by $\frac{\textit{Non-commercial Long Position}-\textit{Non-commercial Short Position}}{\textit{Total Open Interest}}$ following Hedegaard (2011) and liquidity is measured by aggregate open interest. 'Partial' represents a significant impact on a few contracts with different maturities of a particular commodity.

− 0.63) as the maturity of the contracts moves away from underlying contracts. On the other hand, open interest has a positive influence on equity-copper before financialisation. However, since financialisation, open interest negatively impacts equity-oats, and this impact intensifies with increasing contract maturity. For the other commodities, the results remain largely insignificant.

Overall, the result suggests there is limited evidence that either speculative activity or liquidity influences the volatility of the equity and commodity or their volatility connectedness. Up to this point, our focus has been on regression analyses to assess the effect of financialisation on the equity-commodity relationship. In the following section, we investigate whether speculation and liquidity Granger cause the volatility of the equity or the correlation between equity-commodity.

5.2. Granger-causality analysis

This section employs Granger causality testing to explore the causal relationships between speculative activity, open interest, and conditional volatility in commodity futures markets. By incorporating the first differences of variables within a VAR framework, we investigate whether speculative activity and liquidity measures influence volatility dynamics, and whether these relationships vary pre- and during financialisation. The inclusion of financialisation-specific variables, lagged by one week, allows us to assess dynamic feedback mechanisms, following the approaches of Hamilton (1994) and Sanders et al. (2004).

5.2.1. Speculative activity and volatility

Understanding the relationship between speculative activity and market volatility is crucial for assessing the broader implications of financialisation, particularly in assessing whether speculative activity can be utilised for forecasting future market volatility, or if investors adjust their positions based on historical volatility information. To explore this, we analyse whether speculators act as market drivers or trend followers.

Table 7 reports an overview of Granger causality between speculative activity and the volatility of commodity futures. Before financialisation, there is unidirectional causality from speculative activity to conditional volatility in nearly half of the index commodities. This influence is partial for specific commodities, such as cotton and heating oil, where only a subset of maturities exhibit significant causality.[30] Conversely, during financialisation, speculative activity continue to drive conditional volatility in heating oil, coffee, KC wheat, and Chicago wheat, indicating an increasing role of non-commercial traders in influencing market fluctuations rather than responding passively to historical volatility trends. Partial Granger causality is observed for corn, live cattle, feeder cattle, and natural gas.

A notable finding is the bidirectional causality between speculative activity and conditional volatility in cocoa during financialisation. This suggests that volatility in cocoa markets both influences and is influenced by speculative positioning, reflecting dynamic feedback loops. This highlights the interplay between speculative positioning and price discovery, where speculators respond dynamically to market signals while contributing to volatility. In contrast, for metal futures, no significant causal link between speculative activity and volatility is detected in either direction following financialisation, consistent with findings by Manera et al. (2013), who argue that metals are less prone to speculative influences due to their reliance on macroeconomic fundamentals. This finding is contrary to Mutafoglu et al. (2012) who identifies speculators are trend followers.

Table 7: The causal link between speculative activity and the volatility of commodity

Type	Pre-financialisation Period	Financialisation Period
Index	46% $SI \rightarrow \sigma_{com}$	60% $SI \rightarrow \sigma_{com}$ 6.25% $SI \leftrightarrow \sigma_{com}$
Off-index	66.67% $SI \rightarrow \sigma_{com}$	16.67% $SI \rightarrow \sigma_{com}$

Notes: This table presents an overview of the Granger causality test between speculative activity and the conditional volatility of commodity futures for the pre-financialisation and financialisation period. SI, σ_{com}, $\rightarrow$, and $\leftrightarrow$ represent speculative activity, conditional volatility of commodity futures, unidirectional causality, and bidirectional causality respectively.

For off-index commodities, speculative activity Granger-causes volatility in 66.67% of cases pre-financialisation but only in 16.67% during financialisation. Notably, Minneapolis wheat consistently exhibits causality across all contracts, reflecting its sensitivity to speculative flows. Conversely, most off-index commodities, excluding lumber, show no significant causal link, highlighting the differential impact of financialisation across commodity classes.

These findings underscore that financialisation, as measured by long-term speculative activity, has a discernible impact on the volatility of specific commodities, particularly index commodities. Thus, it can be inferred that speculative trading may drive long-term volatility fluctuations in certain commodities. For example, our findings corroborate Algieri and Leccadito (2019) provide evidence of speculation Granger causing volatility in energy commodities, although our result indicate this effect only in a few natural gas contracts. This observation supports our hypothesis that financialisation, or a measure of long-term speculative activity, may have a more pronounced impact on the volatility of index commodities compared to off-index commodities. However, they contradict Sanders et al. (2004), Büyükşahin and Harris (2011), Mutafoglu et al. (2012), who find that speculation does not precede volatility. This

[30] These results are available in the online appendix.

Table 8: The causal link between liquidity and the volatility of commodity futures

Type	Pre-financialisation Period	Financialisation Period
Index	40% $OI \rightarrow \sigma_{com}$	46% $OI \rightarrow \sigma_{com}$
Off-index	66.67% $OI \rightarrow \sigma_{com}$	50% $OI \rightarrow \sigma_{com}$

Notes: This table presents an overview of the Granger causality test between liquidity and the conditional volatility of commodity futures. OI, σ_{com} and $\rightarrow$ is aggregated open interest representing liquidity, conditional volatility of commodity futures and unidirectional causality respectively.

discrepancy may stem from differences in data frequency or the proxies used for speculative activity, as our measures explicitly capture long-term speculative intensity.

The Granger causality analysis underscores the evolving role of speculative activity in driving commodity market volatility during financialisation. Index commodities, in particular, exhibit heightened sensitivity to speculative flows, reflecting the influence of passive investment strategies and financialisation-induced systemic risks. By contrast, the impact on off-index commodities remains limited, with physical fundamentals playing a stabilising role. These findings contribute to a deeper understanding of the economic mechanisms underpinning commodity price dynamics, offering valuable insights for policymakers and market participants navigating the complexities of financialised commodity markets.

5.2.2. Liquidity and volatility

This subsection examines the relationship between liquidity, represented by open interest ($OI_{i,t}$), and conditional volatility ($\sigma_{ij,t}$) in equity and commodity markets. Using Granger causality tests, we investigate whether liquidity serves as a driver of market volatility or if the reverse holds true, both before and during the financialisation period. Table 8 summarises the key findings.

During the pre-financialisation period, we observe that liquidity Granger-causes conditional volatility for soybean oil, gold, and lumber. Additionally, partial Granger causality is also observed in livestock and some index and off-index commodities. One notable observation is the maturity of the livestock commodity futures contract increases, open interest loose causality link to the volatility of distant contracts. This suggests that nearby contracts are more liquid than deferred contracts, making open interest more predictive for nearby contracts.

These results align with the economic mechanism that open interest, as a measure of market depth, enhances price stability in more liquid nearby contracts by reducing the impact of transient shocks. The findings is consistent with (Fung and Patterson, 1999), who argue that liquidity is a primary consideration for investors during this period, with little evidence of price volatility influencing liquidity. Investors appear to base their decisions predominantly on market depth rather than reacting to short-term price fluctuations.

Since financialisation, the Granger causality tests report a shift in the dynamics between liquidity and volatility. For commodities like lumber and live cattle, conditional volatility Granger-causes liquidity, suggesting that changes in market volatility influence investor behaviour and trading volume, consistent with financialised trading strategies. Conversely, open interest continues to Granger-cause volatility in sugar, cocoa, heating oil, and specific contracts of Chicago wheat, KC wheat, soybean meal, and feeder cattle. However, as observed in the pre-financialisation period, the explanatory power of open interest diminishes with contract maturity, indicating that liquidity primarily influences nearby contracts. The diminishing influence of liquidity on deferred contracts highlights the time-varying nature of the liquidity-volatility relationship. Nearby contracts, which are more actively traded, are better positioned to absorb speculative shocks, reducing their impact on price volatility. This is consistent with Geman and Ohana (2009), who highlight the stabilising role of liquidity in short-term price dynamics but note its reduced impact on deferred contracts.

5.2.2.1. Speculative activity and correlation. This section examines the relationship between speculative activity and the conditional correlation (ρ_{eq-com}) between equity markets and commodity futures. Table 9 presents the Granger causality results, offering insights into how speculative activity influences cross-market dynamics.

Table 9: The causal link between speculative activity and the correlation between equity and commodity futures

Type	**Pre-financialisation Period**	**Financialisation Period**
Index	31.25% $SI \rightarrow \rho_{eq-com}$	18.75% $SI \rightarrow \rho_{eq-com}$
Off-index	33.33% $SI \rightarrow \rho_{eq-com}$	16.67% $SI \rightarrow \rho_{eq-com}$

Notes: This table presents an overview of the Granger causality test between speculation and the conditional correlation between equity and commodity futures. SI, ρ_{eq-com}, and $\rightarrow$ represent speculative activity, the conditional correlation between equity and commodity futures, and unidirectional causality, respectively.

Before financialisation, several equity-commodity pairs, such as soybean meal, rough rice, coffee, cocoa, natural gas, and selected contracts of soybeans, cotton, live cattle, and feeder cattle- exhibit Granger causality from the speculative activity to conditional correlation. This finding aligns with the theory that speculative flows enhance cross-market linkages by introducing systemic risk factors, as noted by Tang (2012) and Basak and Pavlova (2016). These dynamics reflect the role of speculative activity in aligning commodity markets with broader macroeconomic trends, particularly in index commodities. However, this integration appears to heighten correlations during periods of market stress, challenging the diversification potential of commodity markets.

Post-financialisation, the Granger causality from speculative activity to conditional correlations becomes less prevalent, observed only in cases such as Chicago wheat, gold, and specific contracts of oats, sugar, and cocoa. This decline suggests a shift in the mechanisms linking equity and commodity markets. Financialisation has likely introduced new drivers, such as institutional benchmarking and index investment strategies, which dilute the direct influence of speculative activity on equity-commodity correlations. This aligns with Basak and Pavlova (2016), who argue that passive investment reduces the role of individual speculative flows in determining market linkages. The diminishing influence of speculative activity post-financialisation may reflect the stabilising role of macroeconomic fundamentals, such

Table 10: The causal link between liquidity and the correlation of equity-commodity futures

Type	Pre-financialisation Period	Financialisation Period
Index	6.25% $OI \rightarrow \rho_{eq-com}$	18.75% $OI \rightarrow \rho_{eq-com}$
Off-index	No causal link	33.33% $OI \rightarrow \rho_{eq-com}$

Notes: This table presents an overview of the Granger causality test between liquidity and the conditional correlation between equity-commodity futures. OI, ρ_{eq-com} and $\rightarrow$ are aggregated open interest representing liquidity, the conditional correlation between the equity-commodity futures, and unidirectional causality respectively.

as inventory dynamics and seasonal production cycles, which remain dominant in certain off-index commodities (Geman and Ohana, 2009).

5.2.2.2. Liquidity and correlation. The Granger causality analysis reveals that the relationship between liquidity, represented by open interest (OI), and the conditional correlation (ρ_{eq-com}) between equity and commodity futures is less pronounced compared to the link between volatility and liquidity. Table 10 summarises the Granger causality results, providing insights into how liquidity influences cross-market correlations before and during the financialisation period.

Before financialisation, there is minimal evidence of causality between open interest and conditional correlation. The only significant case is the equity-copper pair, where liquidity Granger-causes changes in the conditional correlation. This limited relationship aligns with the pre-financialisation role of open interest as a measure of market depth rather than a driver of systemic linkages. This finding may reflect the dominance of fundamental market dynamics, such as inventory cycles and supply-demand shocks, in shaping commodity prices and correlations during this period.

The reverse causality observed in equity-soybeans correlations could be due to the role of macroeconomic shocks and trade policies in driving investor behaviour, consistent with the feedback mechanisms. Moreover, the emergence of causal links in off-index commodities post-financialisation, such as orange juice and live cattle, suggests that liquidity influences correlations differently across sectors. This heterogeneity highlights the varying impacts of financialisation on commodities with distinct market structures and fundamentals

These findings build on the literature by demonstrating the evolving role of liquidity in financialised markets. While Fung and Patterson (1999) emphasise the limited impact of liquidity on pre-financialisation correlations, our results align with Basak and Pavlova (2016) and Tang (2012), who highlight the increasing influence of liquidity on systemic linkages in financialised markets. The observed feedback loops further expand on Schneider and Tavin (2024), illustrating the dynamic interplay between price discovery, liquidity, and correlation structures.

To sum up, we find the causal link from speculative activity to conditional volatility of majority index commodities (except in metal futures, soybeans-related futures, sugar, and cocoa) to strengthen while this causal link barely exists for off-index commodities since the financialisation. Therefore it can be concluded that a non-commercial position can be useful in predicting price variation in index commodities.

The empirical analysis highlights significant changes in volatility connections between equity and commodity futures markets as a result of financialisation. The change in price volatility of these markets can be explained partly by the financialisation process. In general, financial investors try to minimise their risk exposure by entering to commodity futures market increasing speculative activity. This increase in speculative activity increases the open interest in the market, providing additional pricing information and boosting liquidity in the commodity markets. This, in turn, contributes to price stability and decreases price volatility in these markets. Furthermore, financialisation has altered the co-movement between the equity and commodity futures markets. As hypothesised, the seasonality effect in volatility diminishes since financialisation. Moreover, Samuelson's maturity effects are prevalent in all commodities except for metals. The most striking result to emerge from the analysis is the inverse effect of Samuelson's correlation between equity-commodities since the financialisation of commodities. This suggests a fundamental shift in the relationship between equity and commodity prices, with financialisation altering the traditional patterns of market connectedness.

6. Discussion: Evolving Dynamics in Equity-Commodity Markets under Financialisation

This paper examines the intricate dynamics between equity and commodity futures markets, exploring how financialisation has reshaped traditional mechanisms like seasonality, volatility, and correlations. By integrating the findings with existing literature and theoretical frameworks, this discussion highlights the broader economic mechanisms and contributions to market understanding.

6.1. Speculative Flows and Price Dynamics

Financialisation has significantly amplified speculative flows in commodity markets, shifting price drivers from supply-demand fundamentals to macroeconomic signals and systemic risks. As noted by Cheng and Xiong (2014) and Tang (2012) Speculative intensity, particularly through index investment, has led to increased co-movement between equity and commodity markets, which this paper observes empirically. This finding is consistent with Henderson et al. (2014), who argue that non-information-based flows, such as those from exchange-traded funds, significantly impact commodity price dynamics.

The speculative activity that drove market distortions during the 2007-2008 crisis continues to play a role in altering volatility structures, especially in energy and metals. Schneider and Tavin (2024) and Carter and Revoredo-Giha (2023) demonstrate how speculative activity intensifies systemic risk linkages and distorts price discovery processes. These speculative flows complicate the use of commodities for hedging and risk management, as evidenced by the increased volatility across commodity futures markets.

6.2. *Risk Sharing, Convenience Yield, Inventory and Market Structure*

The transformation of risk-sharing dynamics due to financialisation is central to the observed diminishing of Samuelson effects. Basak and Pavlova (2016) argue that institutional investors, such as those using exchange-traded funds (ETFs), have introduced new channels for risk transfer, aligning commodity futures more closely with equity markets. This institutional influence increases correlations across asset classes, diminishing commodities' traditional role as diversification tools.

The weakening of the Samuelson maturity effect in the paper is consistent with the literature on convenience yields and risk-sharing. As suggested by Schneider and Tavin (2024), inventory management practices and reduced storage costs under financialisation have lessened the impact of physical supply-demand constraints on futures prices. This structural change shifts the primary drivers of volatility from inventory cycles to broader financial flows, particularly for index commodities.

The role of convenience yields and storage costs, as formalised in the theory of storage (Kaldor, 1939), is evident in the maturity effects observed in non-metal commodities. High inventories and storage costs create upward-sloping term structures, while depleted inventories drive backwardation. Our findings corroborate with the results of Han et al. (2024), who note that time-varying convenience yields predominantly drive commodity price variations over long horizons.

6.3. *Seasonality and Volatility*

The seasonal variations observed in commodity futures returns and volatility are another significant finding of this study. Seasonality is particularly pronounced in agricultural and energy commodities, reflecting production cycles, climatic conditions, and consumption patterns. These findings are consistent with Geman and Ohana (2009), who emphasise the role of natural seasonal factors in shaping commodity price dynamics.

Post-financialisation, seasonal effects in index commodities have weakened, a trend attributed to the increased influence of financial factors, such as index-tracking strategies and passive fund flows. These strategies align commodity prices more closely with equity markets, diminishing their responsiveness to seasonal supply-demand fluctuations (Basak and Pavlova, 2016).

The attenuation of seasonality due to financialisation has consequences on futures prices, with implications for their role in price discovery, hedging, and risk management. For instance, it can weaken the critical signals for market participants, reducing the utility of futures prices as predictors of spot market conditions. Moreover, seasonal price differences contribute to the shape of the futures curve (e.g., contango during surplus periods, backwardation during tight supply periods). The weakened seasonality can lead to flatter curves, which may obscure traditional signals of supply-demand imbalances. Additionally, many hedging strategies rely on predictable seasonal price movements to lock in prices for future delivery. If seasonality diminishes, producers, consumers, and intermediaries may find it harder to structure effective hedges, increasing exposure to price risk.

6.4. The Samuelson Effects: Maturity and Correlation

The Samuelson maturity effect, which predicts a decline in volatility as futures contracts approach expiration, reflects the influence of storage, risk sharing, and information dynamics in commodity markets. Our analysis confirms the presence of this effect in pre-financialisation periods for most commodities but finds significant deviations since financialisation.

The 'inverse Samuelson correlation effect' fundamentally alters our understanding of price discovery and information flow in financialised markets. Traditionally, nearby contracts reflects short-term, commodity-specific shocks with lower systemic risk linkage, while distant contracts are less volatile and less connected to systemic risks. Financialisation disrupts this dynamic, aligning distant contracts more closely with macroeconomic conditions and equity markets.

The observed diminishing or inverse Samuelson effects in certain commodities align with findings by Schneider and Tavin (2024) and Basak and Pavlova (2016), highlighting the role of speculative activity and liquidity dynamics. Increased market liquidity, driven by financialisation, has reduced the sensitivity of distant contracts to traditional supply-demand fundamentals, thereby flattening volatility gradients. Additionally, passive investment strategies, such as ETFs, amplify volatility across maturities by inducing systematic trading patterns, as demonstrated by Todorova (2004).

This shift suggests a dual role for futures markets in price discovery: nearby contracts still capture short-term shocks, but distant contracts increasingly integrate long-term financial risks and systemic information. This reconfiguration dilutes the unique informational value of nearby contracts and complicates their use for price discovery and risk management.

Excess co-movement and systemic volatility between equities and commodity futures highlight increased cross-asset spillovers, reducing the diversification benefits of commodities. Furthermore, these dynamics challenge traditional asset pricing models, such as the theory of storage, which must now account for time-varying risk premia and the influence of speculative activity.

6.5. Economic Mechanism and Policy Implications

The financialisation of commodity markets has profound implications for market efficiency, particularly in price discovery and risk management. Traditional theories posit that futures markets are efficient when prices reflect all available information, enabling effective hedging and investment decisions. However, the findings in this paper suggest that financialisation introduces complexities that challenge this efficiency.

Financialisation has transformed commodity markets, offering liquidity and risk-sharing benefits, while introducing systemic risks and distortions in price discovery which may reduce the informational efficiency in the market. The attenuation of seasonality in commodity prices, especially in agricultural and energy markets, reflects a fundamental change in market structure. As noted by Gorton and Geert Rouwenhorst (2006), financial investors' dominance has reduced the influence of supply-demand cycles, leading to more stable but less fundamentally-driven markets. This has critical implications for risk management and policy.

This study underscores the need for enhanced regulatory measures, such as stricter reporting requirements for speculative positions and tailored oversight for index-linked financial products. These interventions could mitigate the destabilising effects of speculative flows while preserving the hedging and price discovery functions of futures markets.

7. Robustness

In order to analyse if the main results vary under several conditions. We adopt three types of robustness checks: (1) econometric method, (2) different measures of speculation and (3) detrended open interest series.[31]

For the econometric method, we use AR(1)- DCC MGARCH specifying conditional mean and conditional variance similar to our previous model. We find similar ARCH, and GARCH effects including seasonal effects in the variation in prices as our main model.

In terms of different speculation measures, we use speculation measures following Robles et al. (2009) and Sanders et al. (2010).[32] We observe that change in speculation measure shows some evidence of change in the relationship between correlation and speculative activity and volatility and speculative activity.

A natural question is whether our result is affected by an increasing pattern of open interest. To address this, we detrend open interest series by using a dummy variable for each week within a season and conduct the analysis. Even after detrending the series, open interest yielded similar results. This suggests that open interest *per se* is not alone responsible for the increasing volatility and the integration of equity and commodity markets.

Taken together, these finding suggests the robustness of our main results except in some cases of using a different measure of speculative activity. The difference in results indicates the requirement for a common speculation index for financialisation measures to carry out future research.

8. Conclusion

This paper provides a comprehensive analysis of the evolving dynamics between commodity futures and equity markets, particularly in the context of financialisation. Our findings

[31]These results are available from the author on request.

[32]The first measure following Robles et al. (2009): Speculation Index = $\frac{\text{Non-commercial Long Position}}{\text{Total Open Interest}}$ and the second measure following Sanders et al. (2010): Speculative Pressure = $\frac{\text{NCL-NCS}}{\text{NCL+NCS}}$, where NCL represents the non-commercial long position and NCS represent the non-commercial short position.

contribute to the growing body of literature that highlights the transformative effects of financialisation on market behaviour, price volatility, and cross-asset connectedness. By integrating insights from empirical results and theoretical perspectives, we offer a nuanced understanding of how these markets have changed since the enactment of the Commodity Futures Modernisation Act.

Our analysis reveals a significant shift in the co-movement between commodity futures and equity markets post-financialisation. While pre-financialisation periods exhibited stronger connectedness during low-volatility phases, the post-financialisation era has been characterised by intensified linkages during periods of heightened market stress. This finding aligns with the literature, including Pinto-Ávalos et al. (2024), which documents the increasing correlation between equities and commodities during financial crises. These observations suggest that financialisation has introduced systemic risk factors, making commodities more responsive to broader financial market dynamics.

The increasing volatility and connectedness of these markets have profound implications for financial regulation, risk management, and global economic stability. Our results underscore the need for updated regulatory frameworks and advanced risk mitigation strategies to address the emerging challenges posed by financialisation. Effective policy interventions can help mitigate systemic risks and enhance market efficiency.

One of the key findings of this study is the diminishing role of seasonality in commodity price volatility post-financialisation. This is particularly evident in energy markets, where seasonal patterns were traditionally driven by supply-demand cycles. The attenuation of seasonality supports the hypothesis that commodities are increasingly treated as financial assets, with price movements driven by speculative activity rather than traditional fundamentals, as suggested by Tang (2012) and Basak and Pavlova (2016).

Our empirical results also reaffirm the presence of the Samuelson maturity effect before financialisation, where long-dated futures contracts exhibited lower volatility than short-term contracts. However, the effect has weakened for index commodities in the post-financialisation period, consistent with the growing influence of speculative flows. Speculative activity appears to have reshaped traditional volatility dynamics, leading to an inverse Samuelson effect in certain cases, where the rate of information flow decreases as contracts near maturity (Anderson and Danthine, 1983).

The findings provide empirical support for the financialisation literature, including studies by Büyükşahin and Robe (2014) and Tang (2012), which document how financial flows have amplified price volatility and increased equity-commodity correlations. These dynamics are further complicated by distinct behavioural patterns, such as mean reversion and supply-demand shocks, that vary across commodities.

The weakening of Samuelson effects and the inverse correlation observed in some commodities post-financialisation highlight the profound impact of financialisation on market behaviour. However, our results do not find direct evidence linking speculative activity and liquidity to all observed changes, suggesting that additional factors, such as geopolitical risks and global trade policies, may also play a role. These complexities demand further exploration to disentangle the multiple forces shaping modern commodity markets.

While our study provides new insights into the volatility dynamics of commodity futures and their connectedness to equity markets, it raises important questions about the underlying drivers of these changes. Future research could explore the areas (i) Investigate the specific mechanisms through which speculative activity and liquidity influence volatility and correlation patterns, particularly in index commodities, (ii) Examine the interaction between financialisation and external factors, such as geopolitical events and globalisation, in shaping commodity market dynamics, (iii) extending Schneider and Tavin (2024) model with commodity-specific financialisation measure.

In summary, this paper underscores the multifaceted and evolving nature of commodity markets in the era of financialisation. By linking empirical findings to broader theoretical perspectives, we highlight the significant role of financial flows, speculative activity, and liquidity in shaping volatility and correlation dynamics. These insights contribute to the ongoing discourse on market stability and efficiency, providing a foundation for future research and informed policy interventions.

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