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At the heart of the financial system: A symphony of markets movement and interdependency

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Abstract: This paper explores the interrelationships between commodities, the US dollar, and stock prices, particularly during crises, the COVID-19 pandemic and the Subprime crisis. Using a quantile regression approach, it investigates how financial shocks impact the dependencies among these assets, based on monthly return indices data spanning from January 1995 to August 2024. Findings show significant interactions, with rising oil prices, reducing stock prices and a stronger US dollar negatively affecting both oil and gold prices. Gold acts as a safe haven during economic uncertainty. This research provides valuable insights for investors, policymakers, and risk managers to manage their investment strategies.

في قلب النظام المالي: سيمفونية حركة الأسواق والترابط المتبادل

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المستخلص

يستكشف هذا البحث العلاقات المتبادلة بين السلع الأساسية والدولار الأمريكي وأسعار الأسهم، وخاصة أثناء الأزمات، وجائحة كوفيد-19 وأزمة الرهن العقاري الثانوي. باستخدام نهج الانحدار الكمي، فإنه يحقق في كيفية تأثير الصدمات المالية على التبعيات بين هذه الأصول، بناءً على بيانات مؤشرات العائد الشهرية الممتدة من يناير 1995 إلى أغسطس 2024. تظهر النتائج تفاعلات كبيرة، مع ارتفاع أسعار النفط، وانخفاض أسعار الأسهم، وارتفاع الدولار الأمريكي، مما يؤثر سلبًا على أسعار النفط والذهب. يعمل الذهب كملاذ آمن أثناء عدم اليقين الاقتصادي. يوفر هذا البحث رؤى قيمة للمستثمرين وصناع السياسات ومديري المخاطر لإدارة استراتيجياتهم الاستثمارية.

الكلمات المفتاحية: سوق الأوراق المالية، سعر النفط، سعر الذهب، سعر الصرف، الانحدار الكمي، التبعيات المتبادلة.

1. Introduction

In today's rapidly evolving global economy, understanding the intricate dynamics of financial markets is crucial for both practitioners and academics alike. As markets continue to liberalize and become more interconnected, the movements in asset prices including commodities, exchange rates, or stock indices carry profound implications for both local and international economies. The interconnectedness between key financial indicators performance increasingly shapes investment decisions, regulatory policies, and broader market strategies, making it vital to analyze these trends within a globalized framework.

As noted by Arfaoui and Ben Rejeb (2017), these interrelationships are essential for informed decision-making in a globalized market where financial assets do not move in isolation but are interconnected through complex channels. The complex system of interactions among these assets is increasingly important in times of economic crises when traditional relationships may be altered, leading to unexpected outcomes for investors and policymakers alike.

Financial markets have been profoundly impacted by global crises, such as the COVID-19 pandemic and the Subprime mortgage crisis. For instance, Baur and McDermott (2010) examined the role of gold as both a hedge and a safe haven in times of market distress. Their work provides

critical insights into how asset correlations fluctuate during crises, with gold often acting as a stabilizing force for investors during periods of extreme uncertainty. Similarly, Yilmaz (2010) studied the spillover effects among global equity markets, highlighting the cross-market influence during periods of economic turmoil. The interdependencies between commodities, currencies, and equity markets are complex, and this study looks to contribute to this growing body of research by investigating how these relationships evolve, particularly during crises.

In a rapidly evolving global financial landscape, understanding the interactions between commodities, currencies, and stock markets is becoming increasingly crucial for investors, policymakers, and market analysts. The financialization of commodities has added an additional level of complexity to these relationships. As commodities like oil and gold are no longer viewed solely as physical assets but also as financial instruments, their prices are influenced not only by supply and demand dynamics but also by speculative activity and broader financial market conditions. This financialization, coupled with the turmoil introduced by global crises, has created a more intricate set of dynamics that must be carefully examined.

This paper explores the dynamic relationships between the US dollar, the stock prices, oil and gold prices, with a particular focus on how these relationships evolve during periods of economic turbulence. As the world economy continues to face shocks, including the COVID-19 pandemic and the Subprime crisis, understanding how these crises alter the correlations between financial assets is essential. The methodology applied in this study is the quantile regression, which is an advanced econometric tool to analyze the monthly return indices of these assets from January 1995 to August 2024. Appling this approach, we seek to capture the multifaceted interactions among these variables, particularly during times of crisis, allowing for a more nuanced understanding of the behavior of financial markets.

The application of quantile regression allows us to account for non-linearities and extreme market conditions, providing a more comprehensive analysis compared to traditional methods. Koenker and Bassett (1978) the pioneers of quantile regression, demonstrated its ability to uncover relationships that vary across different points of the conditional distribution, making it an ideal tool for analyzing financial markets during periods of heightened financial fragility, such as those caused by economic crises. This

approach allows us to uncover the fluctuating impact of oil, gold, and the US dollar on stock markets under different market conditions, providing a richer, more detailed view of these interdependencies.

This study provides valuable practical implications for various market participants, including risk managers, policymakers, and investors.

For investors, the study emphasizes the importance of understanding how assets interact during times of economic uncertainty. During crises, traditional relationships between assets, such as between oil, gold, and the US dollar, can shift. For example, gold, often seen as a safe-haven asset, plays a more significant role during financial fragility periods. Investors must remain flexible and adjust their strategies accordingly to diversify their portfolios and better withstand economic shocks.

For policymakers, the findings from this study can inform the development of more targeted economic policies. Given the interconnectedness of financial markets, decisions regarding interest rates, fiscal stimulus, or monetary policies can have global ripple effects. A deeper understanding of these dynamics can help ensure that policies are more effective, particularly during crises.

Finally, risk managers can leverage the study's insights to assess the potential impact of asset fluctuations on their portfolios. The study highlights non-linear interactions between assets, providing a more robust framework for risk management and improving portfolio resilience in times of market turbulence.

This research makes a significant contribution to the existing literature by providing a more nuanced understanding of the complex interdependencies among key financial assets. While many studies have traditionally focused on linear relationships or have examined these assets in isolation, this study adopts a dynamic, non-linear approach to capture the intricate relationships that unfold during crises. Previous studies, such as Khursheed et al. (2014) and Suriani et al. (2015), who have sought to establish simple correlations between variables, but these models often fail to account for the complexities introduced during periods of financial instability.

Further, studies such as those established by Okpezune et al. (2023), Banerjee et al. (2023) and Ardian et al. (2015) who have used VAR and VECM models to analyse the relationships between multiple variables

simultaneously. These models, while useful, do not fully account for the non-linearities and time-varying relationships that are critical during periods of crisis. This study extends the literature by incorporating the approach of quantile regression, which enables the identification of relationships that may vary at different quantiles of the distribution, providing a more granular understanding of asset interactions.

Moreover, while studies such as those conducted by Wang and Chueh (2013), Wang et al. (2023) and Rajwani et al. (2023) which they who have used cointegration models and DCC models to study the dynamic interactions between different markets, this study adds an important dimension by focusing on the role of crises in altering these dynamics. The emphasis on dynamic interactions and the impact of crises makes this research highly relevant in the current global context, where financial markets are increasingly susceptible to external shocks and economic uncertainties.

The structure of this paper is as follows: The second section provides an overview of the relevant literature and the declaration of the research hypotheses. The third section details the methodology and data utilized. The fourth section presents the empirical results and discussion, and the fifth section draws conclusions.

2. **Literature Review and declaration of hypothesis:** The interplay between financial markets and commodity prices has garnered substantial attention in academic literature. To be more precise, the relationships between oil, gold, stock markets, and the US dollar are essential to understanding broader market dynamics (Khursheed et al., 2014; Suriani et al., 2015).

Researchers have explored the complex correlations and causalities that exist between these assets, emphasizing how fluctuations in one can propagate through the others. For instance, gold is often viewed as a safe-haven asset, with its price tending to rise during periods of stock market decline or geopolitical uncertainty (Saidi and Scacciavillani, 2010). Similarly, oil prices have significant impacts on stock markets, particularly in oil-importing countries, as changes in oil prices affect production costs and profit margins for firms (Malairaj, 2017). These reviews focus on the interactions among these markets and propose several hypotheses to guide further empirical testing.

The relationship between oil prices and the US dollar is often characterized by an inverse correlation. Since oil is generally priced in US dollars, fluctuations in the dollar's value can directly influence oil prices. A weaker dollar can make oil cheaper for foreign buyers, thereby increasing demand, while also leading to a rise in oil prices. Conversely, a stronger dollar can dampen oil demand, particularly in non-dollar economies (Yousefi and Wirjanto, 2004). Additionally, rising oil prices can place pressure on the US dollar, especially in oil-importing countries, which may result in currency devaluation (Arfaoui and Ben Rejeb, 2017; De Schryder and Peersman, 2015). Based on these dynamics, we hypothesize the following:

H1: The US dollar exchange rate and oil prices are negatively correlated.

The influence of oil prices on stock markets has been well documented. Oil price fluctuations often have significant effects on stock prices, particularly in oil-importing countries where rising oil prices increase production costs for firms, reducing profitability and lowering stock market performance. In contrast, oil-exporting countries may benefit from rising oil prices, leading to positive stock market performance. Moreover, during periods of economic turbulence, oil price shocks can trigger negative spillovers to the stock market, as evidenced during the 2008 financial crisis (Malairaj, 2017; Robays, 2016; Bekaert et al., 2013). Therefore, we propose the following hypothesis:

H2: The price of oil and the price stock are negatively correlated.

The relationship between oil and gold is particularly relevant in times of economic uncertainty. Both commodities are often seen as hedges against inflation and economic instability. Studies suggest that oil and gold prices can exhibit a positive correlation, especially during periods of crisis when both markets respond similarly to economic shocks. As investors seek safety, they tend to increase their holdings in both oil and gold, driving up prices in both markets Zhang and Wei (2010). This positive correlation can be particularly strong in times of geopolitical tensions or significant economic disruptions Eryiğit (2017). Thus, we expect to observe a negative relation and then we declare that:

H3: There is a positive correlation between the price of oil and gold.

The relationship between stock market prices and gold prices is influenced by risk aversion behaviour. During times of financial market volatility, investors often turn to gold as a safe-haven asset, which results in an inverse relationship between stock market performance and gold prices Arfaoui and Ben Rejeb (2017). This negative relationship is particularly evident during periods of financial crises when stock markets experience significant declines and gold prices tend to rise as investors seek safer assets Gezer (2022). For these reasons we propose the following hypothesis:

H4: The price of gold and stock market have a negative bidirectional relationship.

The negative impact of oil price increases on stock markets is a well-established phenomenon, particularly in oil-importing countries. Higher oil prices increase input costs, reduce corporate profitability, and dampen economic growth, all of which negatively affect stock market performance. The magnitude of this relationship may vary depending on the economic context, but it is generally negative in the short to medium term Okpezune et al. (2023). Furthermore, the effect of oil price shocks on stock prices is more pronounced during periods of high volatility or economic crises (Banerjee et al., 2023; Ardian et al., 2015). Accordingly, we hypothesize:

H5: There is a negative correlation between oil prices and stock market prices.

The relationship between stock market prices and the US dollar is often bidirectional. A stronger dollar may signal confidence in the economy, leading to higher stock prices, as it reflects economic stability and lower inflation expectations. Conversely, a weaker dollar may increase the cost of imports, reduce corporate profits, and negatively impact the stock market. Furthermore, shifts in stock prices can influence exchange rates through capital flows and investor sentiment, making this relationship complex and dynamic (Bekaert et al., 2013; Fratzscher et al., 2014). Thus, we propose the following hypothesis:

H6: stock market prices and the US dollar exchange rate have a negative bidirectional relationship.

In conclusion, each study, using a specific methodology, provides complementary insights into these complex interdependencies. The diversity of the results obtained underlines the need to adopt a multidisciplinary approach to fully understand these phenomena, which guides us towards a new methodology to test this interdependence.

3. Methodology and data

3-1. Methodology: Quantile regression (QR) is communicated by the conditional quantile function $\mathrm{QY|\,X}(\tau)$, it describe the τ^{th} of the conditional distribution of Y given X Koenker and Bassett (1978). We let $q \in [0,1]$ be quantiles 5%, 10%, 25%, 50%, 75%, 90%, 95%. Formulated mathematically, this expressed as:

$$\mathrm{QY|\,X}(\tau) = \inf\{\mathrm{y} : \mathrm{FY|\,X}(\mathrm{y}) \geq \tau\} \qquad \text{(Eq.1)}$$

In which $\mathrm{FY|\,X(y)}$ is the conditional cumulative distribution function of Y given X. In quantile regression, it is assumed that this conditional quantile can be expressed as a linear function of the explanatory variables:

$$\mathrm{QY|\,X}(\tau) = \mathrm{X}\beta\tau \qquad \text{(Eq.2)}$$

Parameter estimators $\beta\tau$ are obtained by minimizing an objective function that weighs the residuals differently depending on whether they are positive or negative, thus making it possible to adapt to different parts of the data distribution (Koenker, 2005; Chernozhukov and Hong, 2003).

QR offers several notable advantages. First, it is robust to outliers, as it does not require residuals to follow a normal distribution, making it more reliable in datasets with extreme values. Second, it enables a comprehensive analysis by estimating relationships at different points in the distribution, which provides a more nuanced view compared to traditional methods that focus only on the mean. Finally, QR is flexible and has widespread applications across fields such as economics, healthcare, and ecology, where relationships may vary across different parts of the distribution.

These advantages make QR particularly suited for analysing financial data, where asset relationships are often non-linear and may change during periods of market instability. In this study, we apply QR to explore how

economic crises influence the interactions between financial assets, offering a deeper understanding of market dynamics.

The linear QR model is written as follows:

$$Q_q(Y_{i,t} / X_{i,t}) = a_i^q + X_{i,t} b_i^q \quad \text{(Eq.3)}$$

Where :

- Y vector is composed by all conditional volatility series

$X_{i,t}$ is the vector of four independent variables:

- The term MSCI (Morgan Stanley Capital International) price refers to the index value that represents the performance of global equity markets. According to Arfaoui and Ben Rejeb (2017), changes in shares can affect gold rates and specially in period of crisis, also there is the possibility of an inverse connection between oil prices and stock market performance. Moreover, highlighting the possible impact of forex trends on stock market behaviour, the detection of recurrent chart patterns in historical forex data has been proposed as a technique to assist traders in making investment decisions Yong et al. (2020). So, we expect a dynamic and evolving interdependence between the stock market, commodities and US exchange rates.
- Gold price alludes to the universal gold cost assign in US dollars, in which research confirms gold is a safe-haven property in various contexts, and studies indicate its role as a safe haven in both conventional and Islamic markets during economic instability Widjaja et al. (2023). For this reason, we expect a very strong interdependence between gold and the other financial asset.
- Oil, this refers to the market price of crude oil, which is a significant commodity in the global economy. Crude oil prices are affected by supply and demand dynamics, economic conditions and crises. More particularly, oil prices are influenced by stock prices, indicating a relationship that investors should monitor closely Howard (2021). We expect a very close relationship between them.
- USD price (the United States dollar) refers to the value of a particular asset, commodity, or currency expressed in US dollars (USD). Studies have highlighted the impact of Forex movements, such as USD, Euro, GBP, and

Yen, on stock market indices, including Nifty 50 and sectoral indices, showcasing a uni-directional relationship in most cases Matha et al. (2022).

Our empirical model is defined as follows as we try to investigate the various effects of conditioning variables on the quantile function in quiet times and during times of financial and health crises:

$$Q_y(q|X) = \lambda(\tau) + \sum_k \alpha_k(q)X_k + D_1\left[\gamma(q) + \sum_k \beta_k(q)X_k\right] + D_2\left[\eta(q) + \sum_k \theta_k(q)X_k\right] + D_3\left[\psi(q) + \sum_k \omega_k(q)X_k\right]$$

(Eq.4)

Where, D_1, D_2 and D_3 are dummy variables for the crises. D_1 for crisis of subprime, D_2 for crisis of covid-19 epidemic and D_3 for both crises. If the dependent variable encounters a financial or health crisis during period "t" they take the value "one", and if not, they take the value "zero."

The quantile we wish to estimate is represented by the parameter q for each quantile (It typically ranges from 0 to 1), the various conditional variables additional marginal effects are provided by $\gamma(q)$ and $\beta_k(q)$ the subprime crisis's parameters, by $\eta(q)$ and $\theta_k(q)$ the COVID-19 crisis's parameters, by $\psi(q)$ and $\omega_k(q)$ parameters in both crisis COVID-19 and subprime crisis, While the parameters identify the effects during normal period $\lambda(q)$ and $\alpha_k(q)$.

Thus, the QR model makes it possible to investigate the interdependencies between each financial asset, from a global perspective. Then, the ways in which various crises (COVID-19 or/and Subprime) impact the dependence structure as a global factor.

3-2. Description of data: A data related to financial markets. It represents various financial variables specifically stocks, US index, oil price, gold price, and their logarithmic transformations.

There are 356 observations, representing a monthly series of return indices, during the time frame from January 1995 to Augst 2024, covering a period of 29 years. The set of data is sourced from Datastream data base, and includes a selection of four markets which are in the MSCI world stock market index, the exchange rate of the US dollar for the foreign exchange market, then the price of crude oil and the price of gold for the commodities

market. Additional controls for monthly data include financial crisis, health crisis, and both crises.

The descriptive statistics in table 1, indicate that the monthly series display common characteristics, including time varying distributions. The table does not report skewness, kurtosis, or jarque-bera and Ljung box tests, as the QR approach makes no assumptions regarding the distribution of the data or the residuals.

Table 1: Descriptive statistic

Variable	Obs	Mean	Std. Dev.	Min	Max
Ln Stocks	356	7.257	0.413	6.410	8.205
Ln USD	356	4.663	0.097	4.490	4.869
Ln OIL	356	3.866	0 .646	2.284	4.888
Ln GOLD	356	6.667	0.713	5.545	7.835

Correlation matrix in table 2, show significant interdependence, between all financial asset gold, oil, USD and stock market. Moreover, Figure 1 illustrates the bivariate dynamic relationships and evolving trends between various assets, more particularly show the interdependencies between the different markets oil, gold, stock and US dollar exchange rates. According to this initial analysis who has improve a strong interdependencies between all assets, it will be more judicious and fundamental to examine the nature of the relationship in more details.

Table 2: Correlation matrix

	Ln Stocks	Ln USD	Ln Oil	Ln GOLD
Ln Stocks	1.0000			
Ln USD	-0.3154*	1.0000		
Ln Oil	0.5626*	-0.3941*	1.0000	
Ln GOLD	0.7647*	-0.5504*	0.8027*	1.0000

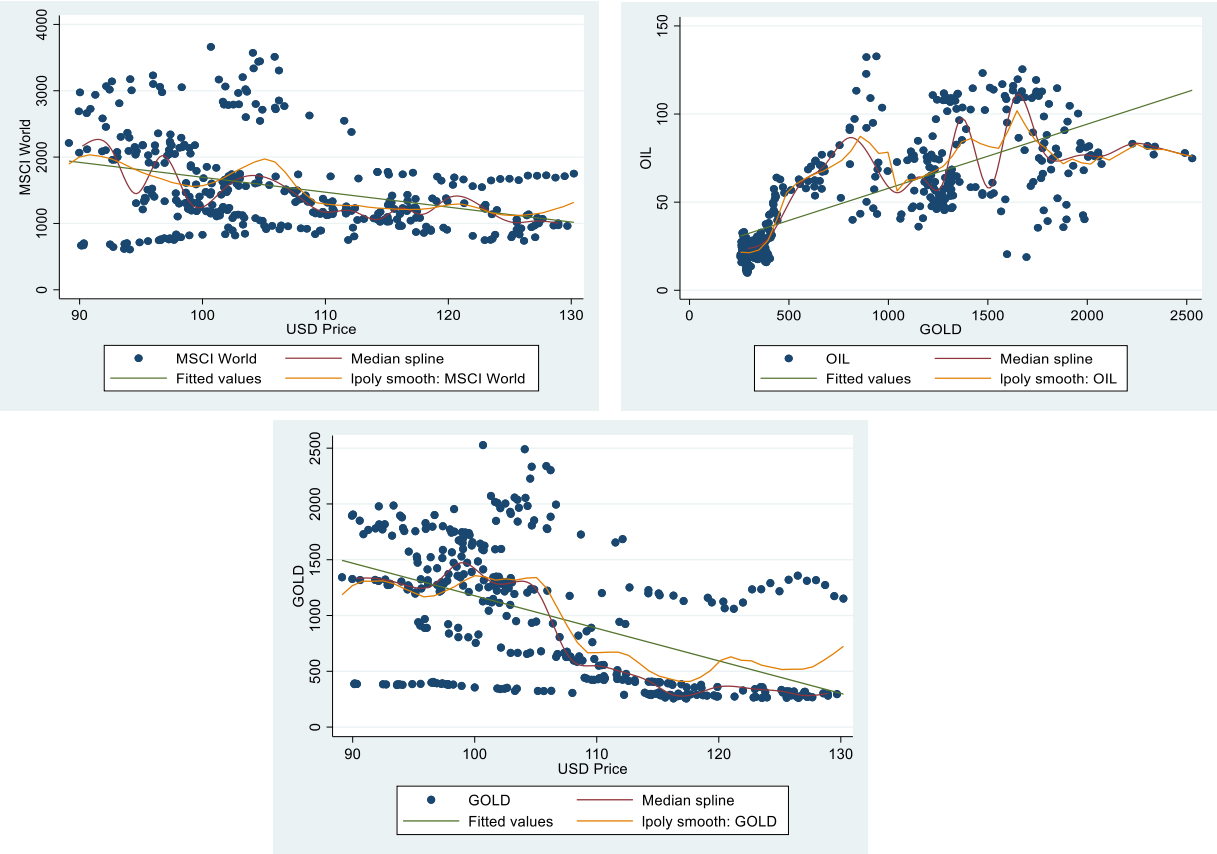

Figure 1. Market trends and interdependencies

4. Results and discussion: In this study, seven quantiles were implemented to analyse and segment the data more precisely, allowing for a detailed assessment of variations within the sample, from the least (q = 0.05) to the highest (q =0.95), and the results acquired from the extreme quantiles additionally to the median (q =0.05, 0.5 and 0.95) are mentioned in the table 3, which allows to estimate tail dependencies carefully.

In fact, these three quantiles allow for the consideration of extreme market conditions, including bearish, mean, and bullish movements, respectively. Also, we can examine specific segments of the data, by focusing on asset performance.

We illustrate, in Figure 2, the graphical results for all quantiles of the conditional distributions of gold prices, oil prices, stock indices, and the US dollar exchange rate, covering all crisis periods, including both calm phases and periods of high financial instability.

The decision rule for determining the potential interdependencies among asset indices relies on the statistical significance of the estimated

coefficients for at least two out of three quantiles. Additionally, an F-test was conducted to analyse the variations in the QR coefficients and assess the equality of coefficients at the extreme quantiles and the median.

Table 3 presents the estimation results from the QR model, which is assumed to appropriately capture and evaluate the interdependencies across the entire distribution. The explanatory power of the exogenous variables at each quantile is generally high. To provide a clearer overview of these findings, a summary is provided in Table 3 and Figure 2.

Table 3. Quantile regression estimates

Dependent variables			MSCI World			USD Price			OIL			GOLD		
Quantile order			Q0.05	Q50	Q95	Q0.05	Q50	Q95	Q0.05	Q50	Q95	Q0.05	Q50	Q95
Independent variables	MSCI World	α				0.181*** (8.83)	0.015 (0.61)	0.021 (1.25)	-0.493*** (-3.55)	-0.396*** (-5.60)	-0.261 (-1.21)	0.704*** (8.95)	0.662*** (11.13)	0.768*** (6.03)
		β				-0.099*** (-2.67)	-0.093*** (-5.00)	-0.085*** (-6.01)	0.557 (1.29)	-0.378 (-1.47)	-0.789*** (-3.39)	-0.549*** (-16.42)	-0.727*** (-11.53)	-0.765*** (-9.60)
		θ				-0.486*** (-4.00)	-0.576*** (-5.55)	-0.409*** (-2.86)	2.627*** (6.16)	2.676*** (13.98)	2.743*** (4.71)	0.418** (2.13)	-0.160 (-1.24)	-0.347* (-1.92)
		ω				-0.029 (-1.01)	-0.069*** (-3.34)	-0.075** (-2.40)	-0.306 (-0.29)	0.504 (0.94)	0.628 (0.90)	0.785 (1.60)	0.761*** (10.23)	0.661*** (11.08)
	USD Price	α	0.424 (0.71)	0.041 (0.10)	0.202 (0.89)				0.862*** (2.83)	0.245 (0.40)	-2.778*** (-9.37)	-3.364*** (-30.22)	-1.797*** (-14.33)	-0.679*** (-2.67)
		β	-5.699** (-2.53)	-8.587*** (-3,40)	-5.228 (-1.45)				-5.195** (-2.22)	-7.895*** (-5.59)	-9.226*** (-9.22)	-5.099*** (-4.71)	-6.632*** (-5.43)	-8.949*** (-6.47)
		θ	-1.726*** (-4.24)	-1.433*** (-13.63)	-1.901*** (-2.71)				5.275** (2.15)	4.108*** (11.50)	5.408*** (5.17)	0.103 (0.28)	-0.624** (-2.26)	-1.286*** (-4.37)
		ω	-0.805 (-0.49)	-1.455*** (-2.77)	-1.060* (-1.88)				-9.224 (-1.64)	1.165 (0.45)	-2.949 (-1.30)	-3.598** (-2.13)	0.675 (1.56)	0.233 (0.44)
	OIL	α	0.102 (0.45)	-0.087** (-2.41)	-0.061 (-0.76)	0.043*** (4.06)	0.017** (2.47)	-0.200*** (-12.06)				0.292*** (8.05)	0.544*** (16.47)	0.443*** (4.74)
		β	-0.178 (-0.72)	-0.698* (-1.62)	-0.467 (-0.82)	-0.058* (-1.96)	-0.092*** (-7.54)	-0.108*** (-12.97)				-0.281** (-2.36)	-0.549*** (-2.86)	-0.970*** (-4.42)
		θ	0.316*** (7.09)	0.333*** (10.60)	0.287*** (3.53)	0.177*** (3.63)	0.207*** (4.43)	0.145*** (3.05)				-0.015 (-0.15)	0.084** (2.00)	0.162** (2.45)
		ω	0.329* (1.65)	0.219*** (7.64)	0.055 0.47	-0.064*** (-6.33)	-0.039 (-1.42)	0.071 (1.08)				-0.317*** (-2.60)	-0.242*** (-3.67)	-0.162** (-2.32)
	GOLD	α	0.264 (1.05)	0.511*** (8.40)	0.503*** (11.22)	-0.221** (-14.16)	-0.110*** (16.25)	0.047** (2.32)	0.981*** (11.15)	0.913*** (8.00)	0.488*** (9.07)			
		β	-0.915* (-1.87)	-1.227*** (-14.85)	-0.929*** (-4.10)	-0.185*** (-3.53)	-0.126*** (-4.41)	-0.111*** (-6.27)	0.386 (0.84)	-0.563** (-2.09)	-1.030*** (-3.76)			
		θ	0.088 (0.81)	-0.300** (-2.32)	-0.160 (-0.18)	0.086 (0.53)	-0.299 (-1.27)	-0.620** (-2.49)	4.674*** (3.14)	0.704 (1.17)	-0.774 (-0.78)			
		ω	1.342*** (3.47)	0.982*** (6.48)	0.560*** (7.91)	-0.129*** (3.53)	-0.060* (-1.77)	0.014 (0.64)	-1.441** (-2.57)	-0.311 (-0.54)	-0.420 (-0.47)			
	$\lambda(\tau)$(Const. Std. est.)		2.682 (0.76)	4.023* (1.72)	3.594*** (3.01)	4.539*** (70.20)	5.216*** (29.11)	5.096*** (96.98)	-3.751*** (-4.36)	-0.479 (-0.14)	16.006*** (7.89)	15.658*** (34.32)	8.158*** (13.49)	3.024 (1.58)
	γ (Subprime Crisis)		33.714*** (2.68)	50.997*** (3.70)	31.723 (1.56)	2.301*** (5.96)	1.910*** (7.14)	1.630*** (8.30)	55.007*** (6.87)	43.407*** (4.35)	18.924 (1.12)	29.785*** (5.57)	37.946*** (5.70)	50.341*** (6.86)
	(COVID Crisis) η		–	8.147*** (7.40)	8.775 (1.00)	2.453* (1.83)	5.857*** (3.47)	7.064*** (3.98)	-78.827*** (-3.92)	-45.052*** (-7.10)	-40.927*** (-5.41)	-1.902 (-0.68)	4.536** (2.27)	7.935*** (3.86)
	(All Crisis) ψ		-6.637 (-0.62)	-0.916 (-0.37)	0.489 (0.17)	1.436*** (10.48)	1.054*** (4.01)	0.005 (0.03)	55.957 (1.62)	-6.655 (-0.45)	11.83803 (1.34)	13.155 (1.11)	-7.078*** (-3.06)	-5.609** (-2.19)
	Pseudo R2(St. Est.)		0.307	0.371	0.4919	0.188	0.286	0.189	0.408	0.434	0.353	0.548	0.642	0.423

Notes: This table presents the quantile regression estimates. The numbers in parentheses are the "t" of Student test. *, ** and *** indicate that coefficients are significant at 10%, 5% and 1% level, respectively. Absolute significance through three quantiles is in bold type. The additional marginal effects of the different conditional variables is given by $\gamma(q)$ and $\beta_k(q)$ parameters in the financial crisis period, by $\eta(q)$ and $\theta_k(q)$ parameters in times of COVID 19 Crisis and by $\psi(q)$ and $\omega_k(q)$ in time of all crisis. While the effects in the calm periods is given by the parameters $\lambda(\tau)$ and $\alpha_k(q)$.

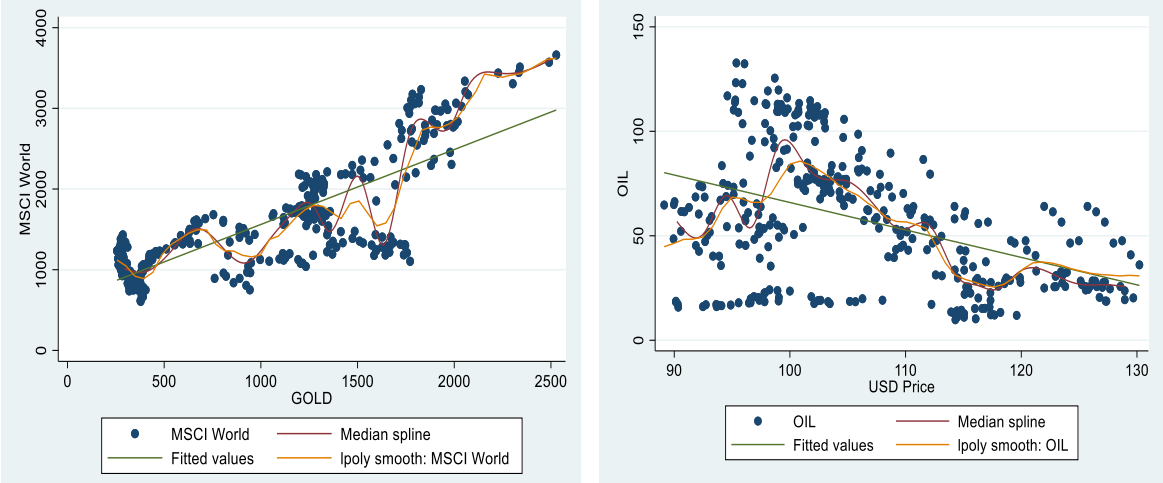

Figure (2): Market trends and interdependencies

The quantile regression coefficients for various assets at three distinct quantiles (0.05, 0.50 and 0.95) are shown in this table. The coefficients are accompanied by t-values, indicating statistical significance. More precisely, we observe strong interdependencies is manifested by an increase in the correlation between the variables at the upper quantiles of the effect distribution, while it decreases at the lower quantiles. These results are statistically significant, thus confirming the hypothesis of a different behaviour of the variables depending on the state of the market. In other words, the relationships between assets are not linear and evolve according to the level of market stress.

4-1. The Interdependency of stock indices: On the one hand the chart suggests a negative relationship between MSCI World index, the USD price, gold price and oil price, but this relationship is complex and non-linear. The general trend suggested is a negative relationship between stock price and all of financial assets (USD price,oil price and gold price). This means that when USD price increases, the world stock index tends to decrease and when the price of oil rises, the world stock index tends to fall. This indicates that the relationship is non-linear, there seem to be periods when the relationship is stronger and others when it is weaker. On the other hand, because gold is frequently viewed as a safe haven, an increase in its price is typically correlated with a decrease in stock price, as a safety net against inflation and during uncertain times. However, this relationship is influenced by many

other factors such as interest rates, monetary policies, geopolitical events, etc. and can vary over time.

Relationship between MSCI and Oil (Black gold)

In general, there is a negative trend between the price of oil and the MSCI World Index. When the price of oil rises, it can lead to higher costs for companies, especially those that rely heavily on energy. This can reduce their profit margins and, as a result, lower stock prices. In addition, a rise in oil can also signal concerns about inflation, causing investors to shift away from stocks to safer assets.

However, this relationship is non-linear; there may be periods when the impact of oil on stock markets is more or less pronounced and especially in periods of crisis, such as in the quantile regression figure we observe a higher impact during the subprime financial crisis and the COVID-19 health crisis.

The invers negative correlation between the price of oil and the stock market support the finding of Banerjee et al. (2023) note that in certain contexts, such as the Dubai market, oil price increases may negatively affect the stock market in the near term. Indeed, Okpezune et al. (2023) who suggest that stock market performance is generally negatively affected by oil price increases in importing countries, supporting the idea of a negative relationship. Recent findings of Atiq et al. (2021) and Robays (2016) Robays, 2016)highlights evidence that oil importing countries experience stock market declines due to oil price increases, while oil exporting countries can benefit.

Thus, we can affirm the fifth hypothesis, which states that there is a negative correlation between the price of oil and stock market.

Relationship between MSCI and the USD

Similarly, the MSCI Index tends to decline when the value of the USD increases. A strong currency makes US exports more expensive for foreign countries, which can negatively affect US corporate revenues and, by extension, stock prices. A rising USD can also mean higher interest rates, which can dampen investment and consumption. Again, this relationship is subject to variation depending on the overall economic context, making the analysis non-linear.

What supports The research of Arfaoui and Ben Rejeb (2017) highlights the interconnectedness between markets, implying that

fluctuations in one market can influence the other, indicating a complex dynamic that can include negative relationships. Furthermore Malairaj (2017) mentions that the merger of markets has intensified the effects of instability, which can translate into negative relationships during periods of financial crisis. Also recent results of (Khursheed et al., 2014; Suriani et al., 2015) indicate that there is no significant correlation between exchange rates and stock prices, suggesting that markets can operate independently. However, this could also support the idea of a negative relationship when stock market movements influence exchange rates. Finally, studies, such as those of Garcia and Rodrigues (2019), reveal unidirectional relationships, but the mention of "changes in exchange rates that can precede changes in stock indices" could also be interpreted as a negative relationship, especially if movements in the dollar affect stock market performance under certain conditions. To conclude, hypothesis six is supported.

Relationship between MSCI and gold

Similarly, the previous two relationships, a rise in the price of gold is often associated with a fall in stock prices. Gold is seen as a safe haven in times of financial fragility or crises. When investors turn to gold, it can be a sign that they anticipate difficulties in the stock markets. However, in contexts of high inflation or accommodative monetary policies, the price of gold can rise while stocks fall. This again shows that this relationship is influenced by many factors.

Moreover, we are dealing with Gezer (2022) who mentions a refuge-seeking behaviour of investors, where stock market movements influence gold returns, suggesting an inverse relationship. Tran and Nguyen (2022) show that in some Asian countries, there is a bidirectional causality between the stock market and the price of gold, which could reflect a negative relationship in specific contexts. Furthermore Arfaoui and Ben Rejeb (2017) indicate that stock variations can influence gold prices, reinforcing the idea of an interconnection where a decline in stocks could correspond to a rise in gold prices. Who maintained that the price of gold and stock market have a negative bidirectional relationship. Then, hypothesis four is verified.

4-2. The interdependency of US dollar

The value of the US dollar is crucial to the world economy and affects the prices of many assets, which are oil, gold, and stocks. The relationships

between the dollar and these assets are complex and can be influenced by a multitude of factors.

The three charts analysed reveal a complex and dynamic interdependence between the US dollar and three major assets. Oil, gold, and stock, all have an inverse relationship with the US dollar. Indeed, when the dollar strengthens, the price of these assets tends to fall. This relationship can be explained by different factors. For oil, the strengthening of the dollar, the reference currency for this commodity, makes imports more expensive for non-US countries, thus reducing demand and therefore the price. Regarding gold, it is less appealing when the dollar, which is regarded as a safer asset, strengthens. Gold is frequently seen as a safe haven in uncertain times. Investors typically purchase dollars with their gold, which lowers the price of the yellow metal. Finally, a strong dollar can harm the competitiveness of US companies' exports, weighing on profits and stock prices. In addition, it attracts foreign capital to the United States, which can lead to outflows from global stock markets.

There is a tendency for the US dollar and the assets under study (stocks, gold, and oil) to become more interdependent during times of high volatility or economic uncertainty. In fact, during these times, investors are compelled to look for safe havens, like the dollar, which amplifies price fluctuations and strengthens correlations between various assets.

Relationship between USD and Gold

The value of the dollar is typically inversely correlated with the price of gold. When the dollar strengthens, gold becomes more expensive for foreign investors, which can reduce demand. In times of economic stability, investors often prefer to hold dollars, which are considered a safe haven asset, rather than holding gold, which does not offer a yield. This explains why a rising dollar can lead to a decline in gold prices. Additionally, in times of uncertainty, gold generally attracts more investment, but when it is less competitive against the strong dollar, its price tends to decline.

The current results support both the theoretical analysis and the body of empirical research. Saidi and Scacciavillani (2010) argue that gold is considered a safe haven asset, and that when the dollar weakens, the price of gold tends to increase to protect against economic uncertainty. Furthermore, Arfaoui and Ben Rejeb (2017) argue that changes in the price of gold can influence capital movements, which in turn can affect the dollar exchange

rate. This suggests a dynamic where the depreciation of the dollar leads to an increase in the price of gold. Furthermore, Wiegand (2019) highlights the importance of gold exporting countries and how fluctuations in the dollar influence gold prices, previously highlighting an inverse relationship.

As a result, we agreed with the second hypothesis, which holds that there is a negative correlation between the value of gold and the US dollar.

Relationship between USD and Oil

The relationship between USD and oil follows a similar pattern. Oil is generally priced in dollars, so when the dollar strengthens, the cost of oil for non-U.S. countries increases, which can decrease aggregate demand. This decline in demand can put downward pressure on oil prices. Additionally, a strong dollar can affect the competitiveness of U.S. exports, which can have implications for the profits of energy companies.

This is what the references have unanimously confirmed, as follows, Siddiqui et al. (2023) show that oil shocks have a significant impact on the exchange rates of oil-producing countries, suggesting that when oil prices rise, this can put pressure on the US dollar, especially in oil-importing countries. Then, Arfaoui and Ben Rejeb (2017) note that rising oil prices can lead to the devaluation of currencies of oil-importing countries, suggesting that the dollar could weaken when oil prices rise. and we conclude with Ardian et al. (2015) also examine how commodity prices, including oil, influence exchange rates over time, reinforcing the idea of a negative correlation between the strength of the US dollar and oil prices.

The third hypothesis, that there is a negative correlation between oil prices and the value of the US dollar is verified.

4-3. The interdependency of Commodities

The interdependency of oil price

The interdependence between the price of oil and other assets is a dynamic phenomenon. It is influenced by a multitude of factors, such as market volatility, global crises, financial integration, exogenous shocks and the sensitivity of economic sectors to energy prices.

The second figure reveals that an increase in the price of oil is generally associated with an increase in stock prices. Similarly, shows that a strengthening of the US dollar is generally associated with a decrease in the price of oil. Finally, it indicates that an increase in the price of gold is generally associated with an increase in the price of oil.

Also, we observe that there is a positive relationship between the price of oil, the price of gold and the stock price while a negative relationship between the US dollar's value and the price of oil, however this relationship is intricate and nonlinear.

Our results suggest that it is necessary to take into account the interdependencies between the oil price and other assets in order to construct efficient portfolios. The sensitivity of markets to oil price fluctuations underlines the importance of closely monitoring the evolution of the geopolitical situation and monetary policies in the context of crisis.

The interdependency of gold

Gold, traditionally considered a safe haven, presents complex dynamics in its relationships with other reference assets. Although it is often perceived as an uncorrelated asset, empirical studies have shown non-linear relationships between gold and indices such as the MSCI or the price of oil. Thus, gold can exhibit negative correlations with these assets during certain market phases, particularly in periods of financial fragility or crises. On the other hand, its correlation with the US dollar is generally positive, suggesting that the dollar remains the world's reserve currency. This direct relationship is explained by the fact that an appreciating dollar can limit the demand for gold as an alternative asset. It is important to emphasize that these relationships are non-linear, which means that the strength and direction of these correlations can vary considerably depending on market conditions.

The couple gold and oil price

Several references unanimously suggest that a positive correlation exists between gold and oil prices, especially during periods of high markets movements and crisis.

First, Eryiğit (2017) shows that the price of oil and gold are positively correlated, particularly during times of market turbulence. The interdependence of the two markets is evident, especially in the context of economic crises.

Second, Nirmala and Kuriakattil (2015) reveals dynamic correlations between gold and oil, indicating that gold price changes can be significantly influenced by oil price changes, and vice versa.

Third, Michele Patanè et al. (2017) demonstrates that oil price fluctuations provide useful clues to anticipate gold price trends, especially during periods of economic turbulence.

Moreover, Wang and Chueh (2013) find a positive short-term impact of oil prices on gold prices, particularly during oil supply shocks, which reinforces the idea of a dynamic and reactive relationship between the two markets. Also, Kanjilal and Ghosh (2017) found that the relationship between gold and oil prices is nonlinear and asymmetric, suggesting that investors adapt their behaviour according to market conditions.

Furthermore, Balcilar and Shahabad (2022) show a strong positive long-term correlation between gold and oil prices, suggesting that the movements of the two assets are often synchronized, particularly in times of crisis. Indeed, Wang et al. (2023) establish a connection between Chinese stock indices, gold prices and oil prices, illustrating how these markets interact in a global economic framework, reinforcing the notion that gold and oil are closely related. Finally, we conclude with Rajwani et al. (2023) who highlight short-term spillovers from the energy market to precious metals markets, which reinforces the interconnection between these two commodities.

The result of our estimation shows that there is a positive correlation between the price of oil and the price of gold, often influenced by economic and crises factors. When the price of oil rises, it can indicate concerns about energy supply, geopolitical tensions or inflation expectations. These factors can also push investors into gold, which is seen as a safe haven. For instance, an increase in oil prices may result in a rise in the demand for gold, which would raise the price of the metal. So, our first hypothesis is verified.

After employing quantile regression analysis to assess the relationships between stock indices, gold, oil, and the US dollar price at different quantiles, we were able to derive several results that indicate significant variation in the coefficients across quantiles. This is particularly evident for the MSCI World index, where the effect is more pronounced at the lower tail, while the impact diminishes considerably at the median. This suggests a lower sensitivity to normal market conditions. In contrast, the reaction of gold prices is pronounced in the upper quantiles, indicating a strong correlation during periods of high turbulence. Oil price dynamics also exhibit a negative response at the lower tail, while the sensitivity to market changes is significantly higher in the extreme quantiles. Indeed, we evaluate the model's goodness-of-fit using the variation distribution and pseudo-R-square, where the pseudo-R-square results (R2) confirm this dynamic,

highlighting the importance of threshold effects in assessing dependencies between these assets. These results are essential for risk management strategies in times of crisis, as observed in recent financial fragility period and crises time.

A visual inspection of the individual plots in Figure 2, suggests notable nonlinear relationships between the return of stock indices, the US dollar, oil, gold. To further substantiate these observations, we conduct additional tests. The Fisher test results also highlight significant associations between the coefficients of the explanatory variables and the quantiles examined.

First, we applied F-test to determine if the coefficients differ significantly from zero across all quantiles for each asset. Then, we tested whether are significant differences in the coefficients at the median and at the extremes, to assess whether return at the median is influenced differently by the explanatory variables compared to the tails of the distribution. These test help identify the presence of significant variations in the factors.

Table 4. Result of the F-Tests for the equality of coefficients across quantiles

	F-test equality across all quantile				F-test equality across median and tails			
	MSCI World	USD Price	OIL	GOLD	MSCI World	USD Price	OIL	GOLD
MSCI World	-	9.49*** (0.000)	0.64 (0.694)	2.76** (0.012)	-	0.16 (0.855)	0.36 (0.697)	0.30 (0.737)
USD Price	5.10*** (0.000)	-	104.14*** (0.000)	29.53*** (0.000)	11.80*** (0.000)	-	262.9*** (0.000)	67.40*** (0.000)
OIL	3.95*** (0.000)	12.44*** (0.000)	-	19.38*** (0.000)	0.38 (0.685)	28.69*** (0.000)	-	24.70*** (0.000)
GOLD	0.76 (0.598)	27.10*** (0.000)	13.52*** (0.000)	-	0.20 (0.819)	32.56*** (0.000)	9.11*** (0.000)	-

Note: This table presents F-tests for the null hypothesis of equality of the slope coefficients for the explanatory variables. The F-tests are based on the coefficients reported in Table 3. Column (1) reports F-tests for the equality of coefficients across all quantiles from the 5th to 95th quantile; column (2) presents F-tests for the equality of coefficients across median and tails (for the 5th, 50th and 95th quantile).

The F-test results confirm these inferences. Indeed, we reject the null hypothesis of equality of coefficients across all quantiles in almost all cases, both at the one percent and five percent levels. The results become stronger when we test the null hypothesis that the coefficients are different from zero between the median and the tails (quantiles 5 and 95). F-tests indicate statistical significance in the majority of cases.

The additional marginal effects of the different conditional variables are captured by the parameters associated with financial crisis periods, COVID-19 crisis periods, and general crisis periods. In the context of the financial crisis, the parameters highlight significant adjustments in the relationships, while those associated with the COVID-19 crisis reveal distinct effects on asset volatilities. Furthermore, general crisis periods also show notable impacts on market dynamics. In contrast, the impact during normal periods is taken by the phase-specific parameters, highlighting the importance of considering the temporal context for an accurate assessment of asset dependencies.

5. Conclusion

This research delves into the interrelationships between key financial assets which included stock indices, the US dollar, gold, and oil. Using quantile regression from January 1995 to August 2024. Applying this approach (QR) brings a new dimension to understanding the relationships between financial assets, allowing the exploration of nonlinear behaviours and heterogeneous dependencies. Also, our study offers valuable insights into how economic and health crises impact the interrelationships between assets, highlighting the importance of a contextual analysis.

The study reveals significant interactions across these markets, revealing negative correlations between the MSCI World Index, oil prices, and the US dollar. Rising oil prices typically pressure stock values, while a stronger dollar can negatively impact exports. Gold, however, acts as a safe haven during market uncertainty, often moving inversely to stock prices. The study also emphasized the heightened impact of crises, such as the 2008 financial crisis and COVID-19, on asset relationships. These crises amplified the effects of explanatory variables, making market dynamics more complex. QR's ability to adapt to non-normal distributions provided valuable insights, highlighting non-linear behaviours and heterogeneous relationships. The findings underscore the importance of considering market conditions and crises when analysing asset dependencies. This research contributes to the literature by offering a nuanced understanding of asset interrelationships, crucial for investment strategies and risk management, especially in volatile times. Overall, the study reinforcing the need for contextual analysis in comprehending the evolving dynamics between financial assets.

Overall, our study highlights the complexity of the relationships between financial assets, illustrating that movements in one market can have profound repercussions on others. Quantile regression, through its flexibility and adaptability, has proven to be a powerful tool for deciphering these interactions, while highlighting the importance of contextual analysis to fully understand market dynamics. This study offers valuable insights for risk managers, policymakers, and investors by highlighting the shifting dynamics of asset interactions during times of crises. It underscores the importance of flexibility in investment strategies, informed policymaking, and enhanced risk assessment to better navigate market variation and financial crises.

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