**The COVID-19 black swan crisis: Reaction and recovery of various financial markets.**

**Abstract**

This paper examines and compares financial market reaction and recovery of four broad classes of financial assets – equity indexes, precious metals, 10-year benchmark bonds and cryptocurrencies, to the COVID-19 pandemic. The data set comprises daily observations of close prices in the selected markets from 17-04-2018 to 20-06-2021. Using the Yang and Zhao (2020) and Koenker and Xiao (2004) quantile unit-root tests for return persistence, we find heterogeneity in reactions and recovery patterns not only across asset classes, but also within them. Specifically, we find strong potential for mean reversion in equity markets even at high levels of shocks. While gold offers limited mean reversion, platinum shows very strong resistance to the COVID. Government bonds show small declines in value to the COVID in addition to high persistence. Cryptocurrencies, as a group, turn out to be the riskiest in the long-term, with more than a 50% decline in value coupled with high degrees of persistence. Our results raise questions as to the safe haven characteristics of the newly-popular Bitcoin. Our findings are useful for policy makers and investors through a better understanding of differences in the potential for mean reversion provided by different asset classes.

**Keywords**: COVID-19 reaction and recovery, quantile unit root test, cryptocurrencies, precious metals.

1. **Introduction**

The rapidly escalated COVID-19 crisis is a classic example of a health crisis that gradually transformed into an economic one. The exponential increase in the number of positive cases and deaths worldwide have prompted drastic measures from governments in the form of quarantine, travel restrictions and remote working, with an aim to flatten the curve of the spread of the virus (Goodell, 2020; Yarovaya et al., 2020a). While these measures may have helped in slowing down the spread of the virus globally, their economic impact has been devastating. In addition to a slowdown in businesses and commerce, the unprecedented uncertainty that surrounds the strain of virus has engulfed global financial markets in panic. As production has slowed down and demand slashed, central banks globally have resorted to extreme monetary and fiscal policy measures to prevent a global recession of the kind witnessed in 2008. In March 2020, the IMF came out with its expectation of the COVID crisis ending up ‘at least as bad’ as that of 2008, only to recover in 2021 (Georgieva, 2020).

The impact of COVID has affected global financial markets almost across all dimensions, ranging from traditional financial assets such as equities, bonds and precious metals to the more contemporary asset classes such as cryptocurrencies.[[1]](#footnote-1) For instance, while global stock markets lost about USD 6 trillion in merely a week between February 24 to 28, 2020, the U.S. S&P 500 lost about USD 5 trillion in the same week, as investors began to dump their holdings in pessimism (Peterson and Thankom, 2020). In addition, geographical stock indices such as Japan’s NIKKEI225, UK’s FTSE, France’s CAC 40, Portugal’s PsI-20, Europe’s EURO STOXX and Israel’s TA125 have all lost between 30 to 42 percent of their value following the COVID-induced panic (Table 1 in paper). Just as with reactivity, recovery in these indices is also different. For instance, on April 10, 2020, the cutoff date chosen for this study, recovery rates varied between 15 to 27% of the lowest value observed as a result of the panic.

Precious metals too suffered a strong reaction to the COVID. While gold prices plummeted only to recover as a result of strong demand for financial investment, silver witnessed its lowest price in 11 years owing to poor industrial demand. Similarly, a sharp decline in auto sales globally severely affected prices for the platinum group metals, or PGM as well (S&P Global, 2020). While platinum, rhodium and iridium suffered the worst shock in values (all exceeding 40% of their pre-pandemic highest values), ruthenium and osmium displayed surprising resistance to the pandemic with barely any fall in value. As with stock market indices, recovery rates differ significantly, with the slowest for osmium as on April 10, 2020 and the highest for rhodium at 75% of the pandemic bottom value.

Even 10-year government or treasury bonds, which are traditionally known for their ‘risk-free’ properties are affected to various degrees due to the pandemic. While all four bonds considered in this study – German, US, French and UK bonds suffer decline in bond values between 5.50 and 6.5%, recovery rates as on April 10 lag behind drastically (see Table 1).

Cryptocurrencies, known for their high volatility and uncertain behaviour have been documented to possess significant hedging, diversifier and safe-haven properties against various other classes of assets. In fact, several studies refer to the Bitcoin, the largest cryptocurrency by trading volume, as the ‘new gold’ in terms of its safe-haven characteristics. Quite contrary to expectation, this rather new class of financial assets is also hugely impacted by the COVID crisis, with declines in value exceeding 50% for the three main cryptocurrencies by trading volume – Bitcoin, Ethereum and Litecoin. This has sparked new investigation into the role of cryptocurrencies as safe havens in turbulent times. For instance, despite that cryptocurrencies can enhance portfolio return (Matkovskyy et al, 2021), Conlon and McGee (2020) document the riskiness of the Bitcoin in times of the COVID crisis. They find that even a small allocation of the Bitcoin to a S&P500 portfolio adds significantly to downside risk. In a similar vein, Conlon et al. (2020) document that both Bitcoin and Ethereum fail to act as safe havens for international equity markets in general.

In the light of the stark differences in both reactivity and recovery of the various financial assets to the same COVID shock, it becomes interesting to examine the potential for each of these classes to bounce to recovery, i.e. revert to original values post the impact of shock. This is an important question since it can help investors and market participants understand the risk characteristics of the various asset classes better. The COVID-19 represents an extraordinary shock of unexpected magnitude. No wonder it has been likened to a ‘black swan’ event for the financial markets by some academics. Even when such shocks may be rare, they happen and given the uncertainty they create, they pose the perfect setting to investigate both return and investor behaviour in such times.

Tendency towards recovery to original values raises the important issue of return persistence, which refers to the stationarity associated with an asset return series. High return persistence is associated with long memory behaviour in the return series, thereby making it difficult for the series to return to its long-term equilibrium value, post-shock. Barkoulas and Baum (1996) show that long memory processes in financial time series could potentially invalidate conclusions based on almost all conventional techniques in asset pricing models that are based on the assumption of Efficiency-Market-Hypothesis-consistent Gaussian distributions. Mean reversion, on the other hand, refers to the tendency of a return series to revert to its long-term ‘normal’. Thus, there is a relationship between persistence and mean reversion (Marques 2004). Higher mean reversion is typically associated with lower risk and uncertainty in the long-run through the ability of the asset returns to auto-correct over time. Investors with relative risk aversion greater than one intend to invest more in stocks that exhibit mean-reverting characteristics (Samuelson, 1988).

Mean reversion in stock markets is well-documented (Fama and French, 1988; Balvers et al., 2000, among others) and the speed of mean reversion is impacted by extreme events like the Great Depression (Poterba and Summers, 1988) and the Cold War (Spierdijk et al., 2012). Results on the mean-reversion characteristics of precious metals and cryptocurrencies are rather mixed.

This paper provides the first empirical evidence on reaction and recovery patterns in the financial markets to the COVID crisis for four different asset classes – equity indices, precious metals, 10-year benchmark bonds and cryptocurrencies covering 15 equity indices, four bond benchmark indices, nine precious metals, and three popular cryptocurrencies, Bitcoin, Ethereum and Litecoin.. Specifically, we aim to investigate the safety net associated with these different asset classes in terms of dealing with the unexpected shock of the crisis and eventually bouncing back to normal levels. In some sense, we attempt to investigate their individual safe haven characteristics in times of extreme turbulence of the kind depicted by the COVID. To the best of our knowledge, this is the first paper that investigates return persistence for financial markets in light of the COVID crisis.

For this purpose, we use the contemporary quantile nonlinear unit root test with covariates of Yang & Zhao (2020) which enables us to identify asymmetries in both the distribution of asset shocks as well as its impact on asset mean reverting behavior in a simple, intuitive and yet effective way (Nikolaou, 2008).

Our empirical results indicate not constant unit root processes in the selected financial assets’ time series, implying high heterogeneity in mean reversion not only across different asset groups, but also within each group. Overall, equity markets tend to bounce back to long-run normal values even at very high degrees of shock.. Government bonds display high persistence. Among all asset classes analysed, cryptocurrency demonstrate the worst ability to revert to normal values, especially at very high levels of shock. These results are particularly interesting given the fact that a mere quick look at cryptocurrencies prices suggest both the highest reactivity and recovery rates among the financial assets studied that could be misleading. Therefore, our test results offer valuable insights into mean reversion behaviour that cannot be extracted merely by a superficial monitoring of the price levels, thereby providing additional value to the broad range of practitioners, investors and financial regulators.

This paper contributes to the existing literature in two main ways. First, it highlights the heterogeneity in reaction, recovery and mean reversion of four different asset classes to the COVID crisis, providing novel empirical evidence on the financial consequences of the pandemic. Second, we provide novel evidence on the safe haven characteristics of popular assets such as gold and the Bitcoin by documenting their poor performance in terms of response to this pandemic. We believe that our results will be of practical use to investors, practitioners and policy-makers alike in better understanding not only the economic consequences of COVID-19, but also make wiser portfolio decisions to minimize downside risk.

The remainder of this paper is organised as follows. Section 2 provides a brief theoretical background of recent COVID-19 papers, and relevant literature on asset mean reversion. Section 3 explains the dataset used in this analysis and discusses price dynamics in the four asset classes before and during the pandemic. Section 4 explains the methodology employed. Section 5 discusses empirical results, while Section 6 concludes with some policy and practical implications.

**2. Background Literature**

*2.1 Black swans and financial markets*

The term “Black swan” first introduced by Taleb (2007) rapidly become popular metaphor for unexpected and unprecedented events affecting stock markets. Taleb defines black swan as event that simultaneously has three following attributes: (i) it is an outlier, as it lies outside the realm of regular expectations, because nothing in the past can convincingly point to its possibility; (ii) it carries an extreme impact; (iii) in spite of its outlier status, human nature makes us concoct explanations for its occurrence after the fact, making it explainable and predictable. The hedging and safe haven properties of various financial assets in the wake of several black swan events has been the subject of much research.

Considering the global financial crisis (hereafter, GFC) of 2008 as a black swan event, Hilal et al (2011) investigate the hedging properties of VIX futures against the S&P500. Bekiros et al. (2017) analyse the impact of black swan events on hedging and diversification properties of gold, exploring the dynamic linkages between gold and BRIC stock market during the GFC. Krupa and Jones (2013) discuss several historical disruptions and technological innovation in energy markets using black swan theory. Taylor and Williams (2009) and Olson et al. (2012) considered the increase in the US-LIBOR spread in August 7, 2007 as a black swan event in money market, while Lin and Tsai (2019) analyze China’s stock market crash on 24th August 2015 using same metaphor. Wang et al. (2019) investigate the effect of a Federal policy change on Japanese gold future prices and find that a negative black swan event causes a short-term decline in gold future prices.

*2. 2. COVID-19 and financial markets*

Yarovaya et al. (2020b) employ the term ‘black swan’ for the COVID-19 pandemics and analyze its impact on herding behavior in cryptocurrency markets. They claim that for relatively immature and inefficient cryptocurrency markets, the COVID-19 is the first major macroeconomic shock, which justifies the use of black swan metaphor. They find that while cryptocurrency herding is contingent upon market movements, the COVID-19 pandemic does not end up amplifying herding behaviour (Yarovaya et al. 2020b). Corbet et al. (2020b) analyze the flight to safety properties of gold and cryptocurrencies during the COVID-19 pandemic, and the results suggest that cryptocurrencies are in fact not acting as safe havens, but instead amplifying the financial contagion caused by it. Jalan, Matkovskyy, Yarovaya (2020) document that during the COVID-19 pandemic, gold-backed cryptocurrencies were susceptible to volatility transmitted from gold markets. Though, unlike gold, this type of the crypto assets was unable to quickly recover from the COVID-19 shock. Goodell (2020) highlights several avenues for COVID-19 research in Finance, contrasting the COVID-19 crisis with previous pandemics. Katsiampa, Yarovaya and Zięba (2021) study co-movements and correlations between Bitcoin and thirty-one of the most-tradable crypto assets during the COVID19 period using high-frequency data. They document changes in patterns of co-movements and correlations during this period. Le, Yarovaya and Nasir (2021) analyze the spillover effect between Fintech stocks and other financial assets (gold, Bitcoin, a global equity index, crude oil, and the US Dollar) during the COVID-19 period and demonstrate that volatility transmission across asset classes was exacerbated during COVID-19. The similar is also documented in Yarovaya, Elsayed, Hammoudeh (2021).

For mature financial markets, Sharif et al. (2020) investigate the reaction of the US stock markets to both COVID-19 and oil shocks in first quarter of 2020. They show that stock markets ended up reacting more severely to the oil price crash than to the pandemic. Corbet et al. (2020a) document a negative impact of COVID-19 on the stock prices of companies containing ‘corona’ in their names, and compare this anomaly to the Dot.com crisis. Gormsen and Koijen (2020) analyse the stock market response to COVID-19 news starting with the initial outbreak of the virus in China. Ramelli and Wagner (2020) further explore the stock market reaction to news and stories related to the COVID-19 providing early evidence of the market reaction to the pandemic.

*2.3. Mean reversion in financial markets*

The presence of mean reversion, i.e. when the null hypothesis of a unit root is rejected, implies that shocks are not accumulated. Literature document that mean-reverting behaviour is a function of numerous factors that can lead to further pricing abnormalities and potential disruption such as market efficiency and company performance (Jalan, Matkovskyy, Poti 2021). Also, as Forbes (1996) document the presence of mean reversion suggests pricing irregularities that are inconsistent with equilibrium asset pricing models.

There is substantial literature on the mean reversion properties of various asset classes. Mean reversion in stock markets is well-documented. Starting with Fama and French (1988), mean reversion has been documented for various stock markets and indices over time (Balvers et al., 2000; Gropp, 2004; Gil-Alana et al. 2015; Adebola et al., 2019; Corbet and Katsiampa, 2020, among others). Mukherji (2011) shows that, although mean reversion in stock returns has weakened in recent decades, it persists, particularly for small company stocks. Nasir and Morgan (2018) discuss practical contradiction regarding central bank policy and the problem of unit roots. Gropp (2004) using a panel method with equal‐weighted industry portfolios, finds evidence of mean reversion for NYSE and NASDAQ stocks during the periods 1926–1998, 1963–1998, and 1973–1998, respectively.

The role of political and economic environments and extreme events on the speed of mean reversion has also been documented (Kim et al., 1991; Poterba and Summers, 1988). For international equity markets over the period 1990-2009, very high speeds of mean reversion are observed during times of high uncertainty such as the World War II, the Cold War and the Energy Crisis of 1979 and Black Monday in 1987 (Spierdijk et al., 2012).

In terms of international (non-US equity indices), Borges (2010) documents persistence in equity returns in France, Germany, UK and Spain. Similar findings of persistence are documented by Caporale et al. (2020) for the FTSE100, DAX30, CAC40, IBEX35 and FTSE MIB40 indices. Gil-Alana (2006), shows that for the DAX, FTSE100, S&P500, CAC40 and Nikkei, the null hypothesis of unit root cannot be rejected, implying persistence in returns. Poon (1996) documents no evidence of mean reversion in the UK stock market. Sauer and Chen (1996) analyze UK stock market total returns over the period 1919 through 1990 and document statistically significant mean reversion only during the pre‐war sub-period.

Results on the mean-reversion characteristics of precious metals are rather mixed, with the greatest contradiction in findings for gold. Cheung and Lai (1993) document evidence of unstable long-term memory behaviour in gold returns. Adebola et al. (2019) finds some evidence of mean reversion in gold prices, while Uludag et al. (2014) document moderate evidence in favour of mean-aversion of gold. Urquhart (2015) investigates the mean reversion properties of gold, silver and platinum over the period January 1987 to September 2014. Using different statistical techniques, he finds that each metal goes through phases of predictability and unpredictability. The paper concludes that of the three metals studied, platinum is the most predictable. Gil-Alana et al. (2015) documents persistence across time for gold, rhodium and palladium due to structural breaks. Lucey and Li (2015) investigate the safe haven properties of gold, silver, platinum and palladium for the U.S. They find that for some periods of time, silver, platinum and palladium act as safe havens (high mean reversion) while gold does not. Adewuyi et al (2020) use linearity structures of metal prices with structural breaks and find evidence of stationarity for gold, palladium, platinum and silver.

There are numerous studies on mean reversion in the new asset class of cryptocurrencies, most of which focus on the Bitcoin. Results, however, remain largely mixed. Urquhart (2016) and Wei (2018) document increasing efficiency over time for the Bitcoin, showing evidence of anti-persistence. Philippe et al. (2018) document long memory and oscillating persistence for the Bitcoin, while Turatti et al. (2020) provide evidence in favour of strong mean-aversion for the Bitcoin. Corbet and Katsiampa (2020) document that Bitcoin exhibits similar asymmetric reverting patterns for minutely, hourly, daily and weekly returns between June 2010 and February 2018. Caporale et al. (2018) studies four cryptocurrencies – Bitcoin, Litecoin, Ripple and Dash over the period 2013-2017 and documents generally high persistence for the cryptocurrency market which varies over time. Jalan, Matkovskyy and Poti (2021) analyse stock market performance of 43 firms from 6 industries (work-from-home companies, stay-at-home companies, Cryptocurrency companies, Bitcoin companies, Coronavirus Vaccine companies and Coronavirus therapeutics companies) and show that more than 50 per cent of the companies demonstrate complete absence of mean reversion, indicating higher risk in the long run. Some of the analysed companies in the work-from-home, cryptocurrency and coronavirus-vaccine groups show reversion only in higher quantiles.

**3. Data and motivation**

We investigate four important financial markets, i.e., equity indexes, precious metals, 10-year benchmark bonds and cryptocurrencies (15 equity indices, four bond benchmark indices, nine precious metals, and three popular cryptocurrencies, Bitcoin, Ethereum and Litecoin). The data set comprises daily observations of close prices in the selected markets from 17-04-2018 to 20-06-2021. This is done to ensure adequate number of observations for the ‘normal’ or pre-pandemic period. Data comes from the EIKON Thomson database. For each financial market considered, the date on which it experienced its lowest value following the pandemic is noted as the corresponding pandemic bottom date. Loss of value between the highest value recorded in 2020 and that on the pandemic bottom date and subsequent recovery or bounce-back is noted in terms of gain in value and time taken to recover. The general descriptive statistics is presented in Appendix (Tables A1-A4).

Table 1 documents loss and recovery patterns for all assets considered in the study. On its pandemic bottom date (12/03/2020), Bitcoin lost 53 % of its maximum value in 2020, but it gained as on 9/04/2020 151.7 % back, that is the second highest absolute value of recovery (after rhodium with 175 %). On the other hand, gold decreased by 12.4 % on 19/03/2020 with later recovery in its value by 118 %. In the bond market, the BD benchmark 10 y. bonds have the most significant drop (6.48%) and very modest recovery. The US 10 y bonds dropped by about 5.97% and recovered at the higher amount, approximately matching the pre-pandemic bottom values in 2020. The indexes decreased by approximately more than 31%, with the most significant decline of the indexes of the UK financial markets (approx. -41%). The recovery performance in the indexes varies from 116.87% for NIKKEI 225 to approx. 127 % for FTSE250 and DJ indexes. Therefore, one can observe different resistance and recovery after the significant shock of COVID-19. Thus, our question is to check how and why the selected time series are resistant to shocks. In other words, to check the persistence (a mean reversion) of the time series across several popular financial assets.

**Table 1 Price dynamics in the main financial markets: pre-pandemic vs. pandemic**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | Maximum in 2020 before a drop  | Pandemic bottom date | Pandemic bottom value, USD | Decrease, % | The maximum after recovery, until 10/04/2020 | Gain in value, %, until 10/04/2020 |
| Cryptocurrencies |
| Bitcoin | 10371.33 | 12/03/2020 | 4857.1 | -53.17 | 7370.11 | 151.74 |
| ETH | 286.27 | 12/03/2020 | 110.3 | -61.47 | 173.36 | 157.17 |
| LTC | 83.31 | 12/03/2020 | 30.09 | -63.88 | 46.58 | 154.80 |
| Precious Metals |
| Gold, Handy & Harman Base $/Troy Oz | 1683.65 | 19/03/2020 | 1474.25 | -12.44 | 1741 | 118.09 |
| Platinum,Free Market $/troy oz | 1025.7 | 19/03/2020 | 586.6 | -42.81 | 747.2 | 127.38 |
| Silver, Handy&Harman (NY) U$/Troy OZ | 18.8 | 18/03/2020 | 12.13 | -35.48 | 15.4 | 126.96 |
| Palladium U$/Troy Ounce | 2781 | 16/03/2020 | 1557 | -44.01 | 2307 | 148.17 |
| Rhodium CIF NWE U$/Ounce | 394443 | 24/03/2020 | 178980 | -54.62 | 313289 | 175.04 |
| Iridium U$/Troy Oz | no effect |
| Ruthenium CIF NWE U$/Ounce | no effect |
| Osmium E/KG | 11917 | 09/03/2020 | 11304 | -5.14 | 11767 | 104.10 |
| S&P GSCI Precious Metal Tot. Ret. - RETURN IND. (OFCL) | 1958.16 | 18/03/2020 | 1680.94 | -14.16 | 2010.33 | 119.60 |
| Bonds |
| BD BENCHMARK 10 YEAR DS GOVT. INDEX  | 199.977 | 19/03/2020 | 187.01 | -6.48 | 193.838 | 103.65 |
| US BENCHMARK 10 YEAR DS GOVT. INDEX  | 176.596 | 18/03/2020 | 166.057 | -5.97 | 175.959 | 105.96 |
| FR BENCHMARK 10 YEAR DS GOVT. INDEX  | 233.838 | 18/03/2020 | 219.567 | -6.10 | 227.679 | 103.69 |
| UK BENCHMARK 10 YEAR DS GOVT. INDEX  | 222.745 | 19/03/2020 | 210.373 | -5.55 | 220.959 | 105.03 |
| Indexes |
| S&P 500 COMPOSITE  | 3386.15 | 23/03/2020 | 2237.4 | -33.92 | 2789.82 | 124.69 |
| DOW JONES INDUSTRIALS | 29551.42 | 23/03/2020 | 18591.93 | -37.09 | 23719.37 | 127.58 |
| NIKKEI 225 STOCK AVERAGE  | 24083.51 | 19/03/2020 | 16552.83 | -31.27 | 19345.77 | 116.87 |
| DAX 30 | 13789 | 18/03/2020 | 8441.71 | -38.78 | 10564.74 | 125.15 |
| IBEX 35 | 10083.6 | 16/03/2020 | 6107.2 | -39.43 | 7070.6 | 115.77 |
| DOW JONES COMPOSITE 65 STOCK AVE  | 9710.01 | 23/03/2020 | 6100.31 | -37.18 | 7804.73 | 127.94 |
| NASDAQ COMPOSITE | 9817.18 | 23/03/2020 | 6860.67 | -30.12 | 8153.58 | 118.85 |
| NASDAQ 100  | 9718.73 | 20/03/2020 | 6994.29 | -28.03 | 8238.53 | 117.79 |
| FTSE 100 | 7674.56 | 23/03/2020 | 4993.89 | -34.93 | 5842.66 | 117.00 |
| FTSE 250  | 21866 | 19/03/2020 | 12829.7 | -41.33 | 16407.92 | 127.89 |
| FRANCE CAC 40  | 6111.24 | 18/03/2020 | 3754.84 | -38.56 | 4506.85 | 120.03 |
| PORTUGAL PSI-20 | 5435.85 | 19/03/2020 | 3596.08 | -33.85 | 4196.31 | 116.69 |
| EURO STOXX  | 421.344 | 18/03/2020 | 261.534 | -37.93 | 315.993 | 120.82 |
| EURO STOXX 50  | 3865.177 | 18/03/2020 | 2385.823 | -38.27 | 2892.794 | 121.25 |
| ISRAEL TA 125 | 1684.12 | 23/03/2020 | 1105.95 | -34.33 | 1312.52 | 118.68 |

**2. Methodology**

One of the effective approaches to check mean-reversion behavior is to settle this issue empirically by means of unit root tests. Though, conventional unit root testing procedures (Dickey & Fuller 1979; Phillips & Perron, 1988; Kwiatkowski et al., 1992) have low power to deal with different structural breaks (Perron, 1989; Campbell & Perron ,1991), trend‐stationarity (DeJong et al., 1992), regime‐switching (Nelson et al., 2001), or fractional integration (Diebold & Rudebusch, 1991; Lee & Schmidt, 1996).

Testing for a unit root at the different quantiles allows to define the existence of innovations of a certain magnitude, which reinforce the persistence of the asset prices considered in the study. The existence of a unit root implies that, shocks with a permanent effect are accumulated and build up a stochastic trend, causing a unit root nonstationary and non-mean-reverting. On the other hand, an autoregressive process becomes stationary and mean-reverting due to a shock that has a transitory effect and is offset by a future shock with the opposite sign. Therefore, the unit root test can be regarded as a test for non-stationarity and no mean reversion of the underlying time series.

In literature unit root tests attract attention due to their theoretical and practical significance. Dickey and Fuller (1979) test and the Phillips and Perron (1988) test may lack statistical power given nonlinearity and non-Gaussian conditions. Hansen (1995) approach is a least squares based covariate augmented Dickey-Fuller (CADF) test that includes correlated stationary covariates in the unit root testing regression, showing a more accurate estimate of the autoregressive parameter and an increase in test power. Kapetanios et al. (2003) and Kilic (2011) developed the nonlinear unit root tests based on exponential smooth transition autoregressive models under Gaussian conditions. Koenker and Xiao (2004) proposed a unit root test based on quantile autoregression approach robust under non-Gaussian conditions. Galvao (2009) extends unit root tests based on quantile regression proposed by Koenker and Xiao (2004) allowing stationary covariates and a linear time trend. Then, Yang and Zhao (2020) propose a new test based on a quantile exponential smooth transition autoregressive model with incorporated stationary covariates that increases the test power. Given that the test performs well in finite samples due to including correlated covariates in the testing equation, Yang and Zhao (2020) approach is used in our study and compared to the one of Koenker and Xiao (2004).

A popular augmented Dickey-Fuller (ADF) regression model can be described as follows:

 (1)

where is . Under assumptions that all the roots of are outside the unit circle when , implying that contains a unit root. Otherwise, if , is a stationary process. Denoting the -field generated by {*us, s≤t*} by , the th conditional on quantile of is . Let , , . Then, and the unit-root quantile autoregression is estimated as .

Under the unit-root hypothesis (Koenker & Xiao, 2004):

, (2)

where , , and the long-run covariance matrix of the bivariate Brownian motion is that leads to

, (3)

where , is s a q-dimensional normal variate with covariance matrix ( is independent with ) and , . Following Koenker and Xiao (2004) the limiting distribution of is invariant to the estimations of and the lag length *p*:

, (4)

where is a demeaned Brownian motion. Eq.(3) leads to a robust approach to testing the unit-root hypothesis by means of t-ratio statistics:

, (5)

where is a consistent estimator of , with f and F representing the density and distribution function of , is a vector of lagged dependent variable , is the projection matrix onto the space orthogonal to . Thus, under the unit-root

. (6)

Following Yang and Zhao (2020), a starting point is a univariate two-regime model where follows a unit root process in the middle regime (Kapetanios et al., 2003):

, (7)

where , , , and as , , is the error process, related with other stationary covariates,, where is an m-dimensional stationary covariates, L -is a lag operator, and , is an vector. If approaches 0 it corresponds to a middle regime, and in a case when becomes larger. Thus, Eq. 7 can be specified as:

. (8)

Denoting the -th quantile of and the -th quantile of conditional on , , Eq. (8) can be transformed into:

 (9)

The unit root null hypothesis is then H0 ∶ 𝜃 = 0, and the alternative hypothesis is H1 ∶𝜃 > 0.

Applying a first-order Taylor series expansion, Eq. (9) can be presented as:

 . (10)

Further simplifying Eq. (10), we can write it in the following way:

, (11)

where , and . Solving the following minimization problem yields the estimates:

, (12)

where is the check function following Koenker and Bassett (1978).

Following Galvao (2009) and Yang and Zhao (2020), the quantile nonlinear unit root test with covariates is defined as follows:

, (13)

where is a consistent estimator of , with f and F representing the density and distribution function of , is a vector of lagged dependent variable , is the projection matrix onto the space orthogonal to .

Following Yang and Zhao (2020), under the unit root null hypothesis and the assumptions of Koenker and Xiao (2004), the limiting distribution of t(𝜏) is as follows:

 , (14)

where , and are the standard Brownian motions and independent of one another, , , , . The asymptotic theory for near-integrated processes utilizes the Ornstein-Uhlenbeck process, see Chan and Wei (1987) or Phillips (1987) for more technical details.

In this study we use with denoting the logarithm of closing prices at time *t*, and being the equilibrium (mean) level of , i.e. the unconditional mean of , and is an error term. Thus, is the distance to the stationary mean. The lag orders for the unit root tests are defined by means of the Bayesian information criterion (BIC). For estimation of long-run variance and covariance parameters (𝜎2, *u* and 𝜎u𝜓 ), we use the Bartlett, Parzen kernel and Quadratic Spectral windows in the kernel estimators following Galvao (2009) and Yang and Zhao (2020). Since the results are similar in their magnitude and the same in significance, we present only the results for the Quadratic Spectral kernel estimator. Bandwidth is calculated as in Andrews (1991).

The test statistics for the unit root null hypothesis over the range of quantiles, , are calculated as follows (Galvao 2009; Yang & Zhao 2020):

, (15)

We compare the received statistics with the calculated critical values at the 1%, 5% and 10% levels of significance.

**3. Results and Interpretation**

*3.1. Precious metals*

Results for precious metals in Table 1 reveals significant diversity in the reaction and recovery patterns across selected metals. For instance, the pandemic bottom dates differ significantly across metals, ranging from as early as 09/03/2020 for osmium to 24/03/2020 for Rhodium. While Iridium and Ruthenium remain unaffected by the COVID-19, others are affected to different degrees. The lowest decrease is observed for Osmium (fall in price: 5.14%) on the pandemic bottom day while the most significant decrease is observed for Rhodium(-54.6%). Silver falls by 35 % while Palladium and Platinum by more than 40%. Gold does remarkably well with a decrease of only 12 % on 19/03/2020 with a subsequent recovery of more than the value lost (gain in value: 118 % of lowest value due to the pandemic). The S&P GSCI index that comprises various precious metals loses only about 14% of its highest pre-pandemic value, only to bounce back not only to higher-than-before levels but also surpassing pre-pandemic maximum values (gain in value: 120%).

In terms of recovery, Platinum, silver, palladium and iridium fail to match their corresponding pre-pandemic maximum levels at least till the end of April 10, the cutoff date for the study. These patterns can also be observed in Figure 1 below.

**Fig.1. Losses and gains in the prices of the selected precious metals, sorted by losses, %.**

The losses represent the pandemic bottom value relatively the maximum values in 2020. Gains are the increases relatively to the pandemic bottom values.

To better understand the heterogeneity in reaction and recovery observed for various precious metals, we apply quantile unit root tests to their return series. The objective is to understand, separately for each precious metal considered, and for various magnitudes of shock (quantiles), the persistence in return series and the corresponding scope it offers for mean reversion.

For each metal in the sample, *t*-values are calculated and compared to critical values at different quantiles and levels of significance to determine whether the null hypothesis of the presence of a unit root must be accepted or not. The advantage of this technique is its ability to identify persistence and otherwise of the same return series across different quantiles of the shock to the return series. Thus, it is possible in this manner to observe a return series that offers the scope for mean reversion in some quantiles and not in others. Results are presented in Table 2 (the Koenker and Xiao (2004) test results are reported for comparison in Appendix Table A5).

**Table 2 Tests for quantile unit root, precious metals**

Table shows the results of the quantile nonlinear unit root tests with covariates, *YZtkss*, estimated as in Yang and Zhao (2020). The asymptotic critical values are calculated with significance at the 1%, 5% and 10% levels. The null hypothesis of the presence of a unit root is rejected if the calculated test statistic is lower in value than calculated asymptotic critical values at the 1%(\*\*\*), 5% (\*\*) and 10% (\*) levels of significance. Statistically significant values of *YZtks* are highlighted in bold, while the respective asymptotic critical values that indicate a significance level are underlined.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Quantiles** | ***YZtks*** | **asymptotic critical values** | ***YZtks*** | **asymptotic critical values** |
| **1%** | **5%** | **10%** | **1%** | **5%** | **10%** |
| **Gold** | **Platinum** |
| 0.1 | **-4.778\*\*\*** | -2.736 | -2.065 | -1.705 | -1.422 | -2.870 | -2.204 | -1.847 |
| 0.2 | **-3.106\*\*\*** | -3.020 | -2.367 | -2.020 | **-3.753\*\*\*** | -3.049 | -2.394 | -2.049 |
| 0.3 | -1.621 | -3.175 | -2.532 | -2.192 | **-3.673\*\*\*** | -3.216 | -2.585 | -2.245 |
| 0.4 | -0.603 | -3.301 | -2.701 | -2.380 | **-4.125\*\*\*** | -3.259 | -2.652 | -2.319 |
| 0.5 | 0.706 | -3.251 | -2.639 | -2.305 | -1.742 | -3.267 | -2.665 | -2.334 |
| 0.6 | 0.719 | -3.253 | -2.643 | -2.309 | -0.602 | -3.242 | -2.625 | -2.289 |
| 0.7 | 2.327 | -3.160 | -2.511 | -2.171 | -1.188 | -3.135 | -2.480 | -2.140 |
| 0.8 | 1.711 | -3.014 | -2.362 | -2.014 | -0.548 | -3.040 | -2.386 | -2.040 |
| 0.9 | 2.566 | -2.736 | -2.064 | -1.704 | -1.924 | -2.707 | -2.035 | -1.675 |
|  | **Silver** | **Palladium** |
| 0.1 | **-3.420\*\*\*** | -2.724 | -2.052 | -1.692 | -1.135 | -2.881 | -2.218 | -1.861 |
| 0.2 | **-3.399\*\*\*** | -3.058 | -2.403 | -2.058 | -1.122 | -3.059 | -2.404 | -2.059 |
| 0.3 | **-3.485\*\*\*** | -3.124 | -2.465 | -2.125 | -1.208 | -3.165 | -2.519 | -2.179 |
| 0.4 | -1.421 | -3.177 | -2.534 | -2.194 | -0.038 | -3.208 | -2.575 | -2.235 |
| 0.5 | -0.477 | -3.174 | -2.530 | -2.190 | -0.013 | -3.199 | -2.563 | -2.223 |
| 0.6 | 0.243 | -3.215 | -2.583 | -2.243 | -0.340 | -3.140 | -2.486 | -2.146 |
| 0.7 | 1.397 | -3.132 | -2.476 | -2.136 | -0.001 | -3.158 | -2.509 | -2.169 |
| 0.8 | 1.717 | -3.000 | -2.350 | -2.000 | -0.299 | -3.026 | -2.373 | -2.026 |
| 0.9 | 1.693 | -2.766 | -2.094 | -1.734 | -0.089 | -2.756 | -2.084 | -1.724 |
|  | **Rhodium** | **Osmium** |
| 0.1 | **-4.694\*\*\*** | -2.704 | -2.032 | -1.672 | **-2.6076\*\*** | -2.8326 | -2.1629 | -1.8031 |
| 0.2 | **-5.822\*\*\*** | -2.926 | -2.268 | -1.914 | -2.0426 | -3.1256 | -2.4673 | -2.1273 |
| 0.3 | **-3.536\*\*\*** | -3.056 | -2.401 | -2.056 | **-2.7496\*\*** | -3.2519 | -2.641 | -2.3074 |
| 0.4 | **-2.220\*** | -3.044 | -2.390 | -2.044 | **-3.3045\*\*\*** | -3.2734 | -2.6734 | -2.3444 |
| 0.5 | -0.318 | -3.083 | -2.425 | -2.083 | **-3.9976\*\*\*** | -3.2817 | -2.6817 | -2.355 |
| 0.6 | 2.008 | -3.106 | -2.447 | -2.106 | **-3.1504\*\*** | -3.258 | -2.6508 | -2.3184 |
| 0.7 | 3.484 | -3.089 | -2.431 | -2.089 | -1.9881 | -3.2344 | -2.6131 | -2.276 |
| 0.8 | 2.271 | -3.033 | -2.380 | -2.033 | -1.3322 | -3.1197 | -2.4597 | -2.1197 |
| 0.9 | 1.698 | -2.581 | -1.906 | -1.546 | -0.3624 | -2.6422 | -1.9685 | -1.6085 |
|  | **Iridium** | **GSCI** |
| 0.1 | **-3.597\*\*\*** | -2.752 | -2.080 | -1.720 | 0.000 | -2.409 | -1.730 | -1.370 |
| 0.2 | **-2.924\*\*** | -2.957 | -2.303 | -1.951 | 0.000 | -2.551 | -1.875 | -1.515 |
| 0.3 | -1.313 | -3.086 | -2.428 | -2.086 | 0.000 | -2.742 | -2.071 | -1.711 |
| 0.4 | 0.075 | -3.197 | -2.561 | -2.221 | 0.000 | -2.881 | -2.218 | -1.861 |
| 0.5 | 0.119 | -3.151 | -2.500 | -2.160 | 0.000 | -2.990 | -2.340 | -1.990 |
| 0.6 | 1.832 | -3.114 | -2.454 | -2.114 | 0.000 | -2.571 | -1.896 | -1.536 |
| 0.7 | 2.449 | -3.083 | -2.426 | -2.083 | 0.000 | -2.541 | -1.865 | -1.505 |
| 0.8 | 2.682 | -3.023 | -2.370 | -2.023 | 0.000 | -2.412 | -1.733 | -1.373 |
| 0.9 | 2.781 | -2.841 | -2.172 | -1.813 | 0.080 | -2.566 | -1.891 | -1.531 |
|  | **Ruthenium** |
| 0.1 | **-413.668\*\*\*** | -2.514 | -1.837 | -1.477 |
| 0.2 | 0.000 | -2.562 | -1.886 | -1.526 |
| 0.3 | 0.000 | -2.653 | -1.980 | -1.620 |
| 0.4 | 0.000 | -2.779 | -2.108 | -1.748 |
| 0.5 | 0.000 | -2.870 | -2.205 | -1.848 |
| 0.6 | 0.000 | -2.566 | -1.891 | -1.531 |
| 0.7 | 0.000 | -2.843 | -2.174 | -1.815 |
| 0.8 | 4.856 | -2.715 | -2.043 | -1.683 |
| 0.9 | 3.786 | -2.362 | -1.683 | -1.323 |

For all metals in the sample, significant values are highlighted in bold, indicating the presence of mean reversion, i.e. instances where the null hypothesis of a unit root is rejected, implying that shocks are not accumulated.

Using Yang and Zhao (2020) test (YZ) results, the following observations are made. Gold, traditionally considered a safe haven asset, exhibits mean-reverting behaviour only in the lower quantiles (0.1 to 0.2) of the shock. For silver, we observe tendencies for mean reversion only in quantiles 0.1 -0.3. The different pattern between gold and silver can be explained by the observation of Ciner (2001), who document that in the long – run, these two commodities tend to drift apart. Platinum has a similar pattern to silver. An interesting pattern emerges for ruthenium. While strongly persistent for smaller quantiles, this metal shows mean reversion for the most extreme quantile, 0.1. Similarly, Iridium offers the scope of mean reversion in the first quantiles. In essence, the GSCI index, which comprises several precious metals, shows an absence of mean reversion.

Results using the Koenker and Xiao (2004) tests (KX) are qualitatively similar to those reported above (see Table 5 in Appendix).

In a nutshell, our quantile unit root tests reveal that while gold, rhodium, platinum and silver offer the scope to bounce back to recovery for smaller shocks only. Our results are in line with those of Gil-Alana et al. (2015) who document persistence across time for gold, rhodium and palladium due to structural breaks. With respect to gold, our results are in line with Adebola et al., 2019; Uludag et al., 2014; Cheung and Lai, 1993 and in particular with those of Lucey and Li (2015) who find that for the U.S., gold does not necessarily act as a safe haven and even when it does, it is not the strongest and safest safe haven expected.

It is not surprisingly to see that some of our results contradict observed in Table 1. For instance, gold shows quick recovery after the pandemic bottom to higher-than-before maximum values (recovery rate: 118 percent) while unit root tests indicate limited potential of gold in terms of recovery. Similarly, platinum shows rather sluggish recovery in Table 1, while unit root tests suggest otherwise. Here we must remember that in Table 1, we are looking at a finite period of time starting 2020 and covering the pandemic. Whereas, unit root tests test with respect to a theoretical ‘long-run’ equilibrium, which may not necessarily coincide with the period studied.

Also, another contributing factor could be unexpected events such as structural breaks present in the metals’ time series (Pan, 2018). For instance, Zhao et al. (2015) indicate that gold prices exhibit structural breaks and explosive bubbles during times of crisis. Arouri et al. (2013) support both long–memory in spot and futures prices of gold, silver, platinum and palladium, and the presence of breaks linked with crisis.

*3.2. Equity indexes*

In order to account for geographical differences in the reaction to COVID-19, we have selected a broad range of equity indices (15 in total) covering American indices such as the S&P 500, NASDAQ and Dow Jones, the Japanese NIKKEI, UK’s FTSE, France’s CAC-40, Germany’s DAX, Portugal’s PSI-20, Israel’s TA125, and the European EURO STOXX indexes. One observes a rate of decline in the range of 28 and 42% across indices, with NASDAQ exhibiting the lowest and UK’s FTSE250 recording the highest decline in value. The recovery performance in the indices varies from 115.77% for IBEX35, approximately 117% for FTSE 100, PSI-20 and Nikkei225 to more than 125% for the DAX30, DJ industrial, FTSE250, and DJ65 with the FTSE250 and Dow Jones Industrial and Composite 65 exhibiting the highest recovery rates (nearly 128% of lowest value). UK’s FTSE250 depicts interesting behavior with both very high reactivity and recovery rates (see Table 1 and Fig 2 below).

**Fig. 2. Losses and gains in the prices of the selected stock indexes, sorted by losses, %.**

The losses represent the pandemic bottom value relatively the maximum values in 2020. Gains are the increases relatively to the pandemic bottom values.

The tests of the presence of the mean-reversion processes in the selected equity indexes shows that we can reject the null hypothesis of unit root rather uniformly for all indices for the higher quantiles of the shock. (Table 3; in Appendix Table A7 the Koenker & Xiao (2004) test results are presented for comparison). For instance, for the Dow Jones Industrial, EuroStoxx, EuroStoxx50, FTSE100, FTSE250, Israel TA 125, IBEX 35 and PSI20 we observe mean-reverting behavior for quantiles starting 0.5 till 0.9, suggesting resilience to even very high magnitudes of shocks. For the DAX30, DJ65, CAC40, and NASDAQ composite, mean-reversion is observed for quantiles 0.6 to 0.9. The only exceptions to this general finding of mean reversion in higher quantiles are NASDAQ 100 and the NIKKEI225 for which we observe a unit root for all quantiles, and the S&P500 with mean-reversion only in the 90th quantile. Even when both the YZ and KX tests yield similar results across the various indices studied.

This is a remarkable result in the sense that it sheds light on the high mean-reversion tendencies of stock market indices in general, as a group. This seems to suggest that stock markets in general seem to bounce back to long-run normal values even after significant shocks to their return series. This makes this class of assets more predictable and comparatively less risky in general. This is in sharp contrast to our findings for the cryptocurrency group in this paper which exhibits very strong persistence or long-term memory.

Our results are in line with Balvers et al. (2000), who document significant evidence of full mean reversion in national equity indexes, with a reversion speed of 18 to 20% per year. With respect to mean reversion in France and UK, our results support those of Borges (2010). On the other hand, our results contradict those of Caporale et al. (2020) and Gil-Alana (2006), who document that high persistence for some of the international stock indices selected in this study. For UK, our results support those of Poon (1996) who also finds evidence of mean reversion.

**Table 3 Tests for quantile unit root, stock indexes**

Table shows the results of the quantile nonlinear unit root tests with covariates, *YZtkss*, estimated as in Yang and Zhao (2020). The asymptotic critical values are calculated with significance at the 1%, 5% and 10% levels. The null hypothesis of the presence of a unit root is rejected if the calculated test statistic is lower in value than calculated asymptotic critical values at the 1% (\*\*\*), 5%(\*\*) and 10% (\*) levels of significance. Statistically significant values of *YZtks* are highlighted in bold, while the respective asymptotic critical values that indicate a significance level are underlined.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Quantiles** | ***YZtks*** | **asymptotic critical values** | ***YZtks*** | **asymptotic critical values** |
| **1%** | **5%** | **10%** | **1%** | **5%** | **10%** |
| **S&P500** | **DAX30** |
| 0.1 | 0.154 | -2.604 | -1.929 | -1.569 | 3.873 | -2.804 | -2.133 | -1.773 |
| 0.2 | 0.076 | -2.991 | -2.341 | -1.991 | 3.033 | -3.045 | -2.391 | -2.045 |
| 0.3 | -0.307 | -3.187 | -2.548 | -2.208 | 0.826 | -3.169 | -2.524 | -2.184 |
| 0.4 | -0.514 | -3.221 | -2.592 | -2.252 | -0.660 | -3.202 | -2.567 | -2.227 |
| 0.5 | -1.048 | -3.232 | -2.610 | -2.272 | -2.103 | -3.201 | -2.566 | -2.226 |
| 0.6 | -0.935 | -3.198 | -2.562 | -2.222 | **-3.624\*\*\*** | -3.142 | -2.488 | -2.148 |
| 0.7 | -1.499 | -3.088 | -2.430 | -2.088 | **-5.833\*\*\*** | -3.090 | -2.432 | -2.090 |
| 0.8 | -1.737 | -2.896 | -2.234 | -1.878 | **-6.404\*\*\*** | -2.989 | -2.339 | -1.989 |
| 0.9 | **-1.866\*** | -2.590 | -1.916 | -1.556 | **-4.759\*\*\*** | -2.774 | -2.103 | -1.743 |
|  | **DJ65** | **DJIndustr** |
| 0.1 | 0.831 | -2.644 | -1.970 | -1.610 | 1.164 | -2.615 | -1.941 | -1.581 |
| 0.2 | 0.695 | -2.972 | -2.320 | -1.969 | 0.307 | -2.965 | -2.312 | -1.960 |
| 0.3 | 0.347 | -3.203 | -2.568 | -2.228 | -0.120 | -3.205 | -2.571 | -2.231 |
| 0.4 | -0.862 | -3.222 | -2.593 | -2.253 | -0.886 | -3.231 | -2.608 | -2.270 |
| 0.5 | -1.788 | -3.215 | -2.584 | -2.244 | **-2.355\*\*\*** | -3.237 | -2.617 | -2.281 |
| 0.6 | **-3.104\*\*** | -3.167 | -2.521 | -2.181 | **-2.790\*\*** | -3.204 | -2.569 | -2.229 |
| 0.7 | **-3.308\*\*\*** | -3.082 | -2.425 | -2.082 | **-3.411\*\*\*** | -3.088 | -2.430 | -2.088 |
| 0.8 | **-3.572\*\*\*** | -2.903 | -2.243 | -1.887 | **-3.506\*\*\*** | -2.912 | -2.252 | -1.897 |
| 0.9 | **-2.766\*\*\*** | -2.691 | -2.019 | -1.659 | **-3.078\*\*\*** | -2.581 | -1.906 | -1.546 |
|  | **EuroStoxx** | **EuroStoxx50** |
| 0.1 | 2.946 | -2.770 | -2.099 | -1.739 | 2.689 | -2.843 | -2.174 | -1.815 |
| 0.2 | 1.503 | -3.060 | -2.405 | -2.060 | 2.867 | -3.038 | -2.385 | -2.038 |
| 0.3 | 1.999 | -3.158 | -2.509 | -2.169 | 1.224 | -3.157 | -2.508 | -2.168 |
| 0.4 | -0.744 | -3.217 | -2.586 | -2.246 | -1.218 | -3.220 | -2.590 | -2.250 |
| 0.5 | **-2.827\*\*** | -3.215 | -2.584 | -2.244 | **-4.375\*\*\*** | -3.193 | -2.555 | -2.215 |
| 0.6 | **-3.790\*\*\*** | -3.130 | -2.473 | -2.133 | **-4.075\*\*\*** | -3.101 | -2.442 | -2.101 |
| 0.7 | **-4.116\*\*\*** | -3.017 | -2.365 | -2.017 | **-4.650\*\*\*** | -3.035 | -2.382 | -2.035 |
| 0.8 | **-5.046\*\*\*** | -2.947 | -2.292 | -1.939 | **-4.942\*\*\*** | -2.989 | -2.339 | -1.988 |
| 0.9 | **-8.123\*\*\*** | -2.596 | -1.921 | -1.561 | **-8.073\*\*\*** | -2.581 | -1.906 | -1.546 |
|  | **CAC40** | **FTSE100** |
| 0.1 | 2.845 | -2.770 | -2.098 | -1.738 | 4.661 | -2.610 | -1.936 | -1.576 |
| 0.2 | 3.635 | -3.030 | -2.377 | -2.030 | 2.524 | -3.020 | -2.368 | -2.020 |
| 0.3 | 2.776 | -3.174 | -2.531 | -2.191 | -0.224 | -3.201 | -2.565 | -2.225 |
| 0.4 | 0.313 | -3.202 | -2.567 | -2.227 | -0.961 | -3.201 | -2.565 | -2.225 |
| 0.5 | -1.709 | -3.195 | -2.557 | -2.217 | **-2.894\*\*** | -3.221 | -2.592 | -2.252 |
| 0.6 | **-4.005\*\*\*** | -3.156 | -2.507 | -2.167 | **-6.601\*\*\*** | -3.183 | -2.541 | -2.201 |
| 0.7 | **-4.556\*\*\*** | -3.088 | -2.431 | -2.088 | **-7.523\*\*\*** | -3.070 | -2.413 | -2.070 |
| 0.8 | **-5.929\*\*\*** | -2.932 | -2.274 | -1.921 | **-10.036\*\*\*** | -2.953 | -2.299 | -1.946 |
| 0.9 | **-5.598\*\*\*** | -2.694 | -2.022 | -1.662 | **-11.849\*\*\*** | -2.598 | -1.924 | -1.564 |
|  | **FTSE250** | **Israel TA125** |
| 0.1 | 5.604 | -2.786 | -2.115 | -1.755 | 0.996 | -2.547 | -1.872 | -1.512 |
| 0.2 | 4.401 | -2.991 | -2.341 | -1.991 | -0.394 | -3.006 | -2.354 | -2.006 |
| 0.3 | 2.869 | -3.174 | -2.531 | -2.191 | -0.780 | -3.206 | -2.571 | -2.231 |
| 0.4 | 0.890 | -3.220 | -2.590 | -2.250 | -1.995 | -3.241 | -2.624 | -2.289 |
| 0.5 | **-2.828\*\*** | -3.192 | -2.554 | -2.214 | **-3.329\*\*\*** | -3.231 | -2.608 | -2.271 |
| 0.6 | **-9.155\*\*\*** | -3.073 | -2.417 | -2.073 | **-3.544\*\*\*** | -3.208 | -2.574 | -2.234 |
| 0.7 | **-14.381\*\*\*** | -2.935 | -2.278 | -1.925 | **-4.608\*\*\*** | -3.078 | -2.421 | -2.078 |
| 0.8 | **-12.955\*\*\*** | -2.858 | -2.191 | -1.833 | **-4.904\*\*\*** | -2.939 | -2.282 | -1.929 |
| 0.9 | **-10.761\*\*\*** | -2.514 | -1.837 | -1.477 | **-3.927\*\*\*** | -2.730 | -2.058 | -1.698 |
|  | **IBEX35** | **NASDAQ100** |
| 0.1 | 5.052 | -2.686 | -2.013 | -1.653 | -0.162 | -2.782 | -2.112 | -1.752 |
| 0.2 | 3.540 | -2.983 | -2.332 | -1.981 | -0.238 | -3.021 | -2.369 | -2.021 |
| 0.3 | 0.715 | -3.147 | -2.494 | -2.154 | -1.057 | -3.230 | -2.606 | -2.268 |
| 0.4 | -0.387 | -3.226 | -2.599 | -2.260 | -1.315 | -3.268 | -2.666 | -2.336 |
| 0.5 | **-3.083\*\*** | -3.221 | -2.591 | -2.251 | -0.721 | -3.261 | -2.655 | -2.323 |
| 0.6 | **-5.400\*\*\*** | -3.186 | -2.546 | -2.206 | 0.005 | -3.216 | -2.585 | -2.245 |
| 0.7 | **-7.756\*\*\*** | -3.058 | -2.403 | -2.058 | 0.101 | -3.106 | -2.447 | -2.106 |
| 0.8 | **-9.682\*\*\*** | -2.939 | -2.282 | -1.929 | 0.319 | -2.907 | -2.247 | -1.892 |
| 0.9 | **-9.832\*\*\*** | -2.696 | -2.023 | -1.663 | -0.032 | -2.641 | -1.968 | -1.608 |
|  | **NIKKEI.225** | **PSI20** |
| 0.1 | -0.823 | -2.840 | -2.171 | -1.812 | 4.024 | -2.770 | -2.098 | -1.738 |
| 0.2 | 0.405 | -3.039 | -2.386 | -2.039 | 3.468 | -3.012 | -2.360 | -2.012 |
| 0.3 | 0.081 | -3.225 | -2.598 | -2.259 | 3.441 | -3.121 | -2.461 | -2.121 |
| 0.4 | -0.721 | -3.246 | -2.632 | -2.297 | -0.299 | -3.245 | -2.630 | -2.295 |
| 0.5 | -0.175 | -3.236 | -2.615 | -2.279 | **-5.508\*\*\*** | -3.246 | -2.632 | -2.297 |
| 0.6 | -1.255 | -3.239 | -2.620 | -2.283 | **-5.700\*\*\*** | -3.222 | -2.594 | -2.254 |
| 0.7 | -1.162 | -3.189 | -2.549 | -2.209 | **-7.622\*\*\*** | -3.133 | -2.477 | -2.137 |
| 0.8 | -1.987 | -3.023 | -2.371 | -2.023 | **-9.183\*\*\*** | -2.944 | -2.288 | -1.935 |
| 0.9 | -1.472 | -2.762 | -2.090 | -1.730 | **-8.573\*\*\*** | -2.676 | -2.003 | -1.643 |
|  | **NASDAQ** **COMPOSITE** |
| 0.1 | 5.729 | -2.517 | -1.841 | -1.481 |
| 0.2 | 4.803 | -2.435 | -1.757 | -1.397 |
| 0.3 | 3.576 | -2.440 | -1.762 | -1.402 |
| 0.4 | 1.139 | -2.412 | -1.733 | -1.373 |
| 0.5 | -0.776 | -2.418 | -1.740 | -1.380 |
| 0.6 | **-3.301\*\*\*** | -2.400 | -1.721 | -1.361 |
| 0.7 | **-4.297\*\*\*** | -2.364 | -1.685 | -1.325 |
| 0.8 | **-5.854\*\*\*** | -2.480 | -1.803 | -1.443 |
| 0.9 | **-7.301\*\*\*** | -2.387 | -1.708 | -1.348 |

*3.3. Benchmark 10 year bonds*

Our sample covers 10-year treasury bonds issued by Germany, USA, France and UK. The pandemic bottom dates for all four bonds are very close, i.e., – 18/03/2020 for the US and French bonds, and on the next day for the German and UK government bonds. One observes that for this category, the drop in prices remains rather capped between 5.6 and 6.5% of the highest value in 2020. While the UK bonds suffer the least decline (5.55%), German ones lose the maximum value among the lot (6.48%). Recovery rates remain low too, ranging between 103.65% (German) and 105.96% (US). This seems to suggest that while German bonds demonstrate the highest value decline and poorest recovery after the pandemic bottom day, US bonds not only react less negatively to the shock, but also end up reaching their highest 2020 value post-COVID.

As a broad category, 10-year Treasury bonds represent safety, lower reactivity to the crisis and reasonable rates of recovery post-crisis.

**Fig.3. Losses and gains in the prices of the selected benchmark 10 y. government bonds, sorted by losses, %.**

The losses represent the pandemic bottom value relatively the maximum values in 2020. Gains are the increases relatively to the pandemic bottom values.

Mean reversion test results for bonds are presented in the table below (see Table 4; the Koenker & Xiao (2004) test results are presented in Table A7 in Appendix). A bird’s eye view on the overall results suggests high persistence and the possibility for mean reversion only in very low quantile for UK bonds, while for French bonds we can reject the null for unit root in the higher quantiles. For all other quantiles, a high degree of persistence is observed. It is interesting to compare these results with those from the KX tests. Using the latter, we observe a highly persistent series, with no possibility of mean reversion whatsoever. Our results contradict to some recent studies, e.g., Caporale and Gil-Alana (2019) who find evidence of mean reversion for UK, France and Germany, implying that shocks have transitory effect that disappears in the long run.

Our result can be explained in the light of monetary policy. According to Seo (2003), the persistent behavior of the term spread may depend upon the monetary policy. Rudebusch (1995) and Balduzzi et al. (1997) document that unexpected changes made by monetary authorities can explain future changes in the interest rates. Thus, given that the monetary authorities use interest rates as a tool of economic policy, especially in the conditions COVID-19, the term spread may end up being persistent.

Thus, as a group, 10-year Government bonds display high persistence with German, UK and US bonds being the most persistent of the 4 studied. French bonds show some tendency to mean revert, the possibility remains limited to high quantiles of the shock only.

**Table 4 Tests for quantile unit root, government bonds.**

Table shows the results of the quantile nonlinear unit root tests with covariates, *YZtkss*, estimated as in Yang and Zhao (2020). The asymptotic critical values are calculated with significance at the 1%, 5% and 10% levels. The null hypothesis of the presence of a unit root is rejected if the calculated test statistic is lower in value than calculated asymptotic critical values at the 1% (\*\*\*), 5% (\*\*) and 10% (\*) levels of significance. Statistically significant values of *YZtks* are highlighted in bold, while the respective asymptotic critical values that indicate a significance level are underlined.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Quantiles** | ***YZtks*** | **asymptotic critical values** | ***YZtks*** | **asymptotic critical values** |
| **1%** | **5%** | **10%** | **1%** | **5%** | **10%** |
| **BD BENCHMARK 10 YEAR DS GOVT. INDEX** | **US BENCHMARK 10 YEAR DS GOVT. INDEX**  |
| 0.1 | -0.470 | -2.836 | -2.167 | -1.807 | -1.783 | -2.914 | -2.255 | -1.900 |
| 0.2 | -0.688 | -3.014 | -2.363 | -2.014 | -1.145 | -3.072 | -2.416 | -2.072 |
| 0.3 | -0.866 | -3.226 | -2.599 | -2.260 | -1.104 | -3.194 | -2.556 | -2.216 |
| 0.4 | -1.491 | -3.283 | -2.683 | -2.357 | -0.643 | -3.298 | -2.698 | -2.375 |
| 0.5 | -1.627 | -3.260 | -2.654 | -2.322 | -0.390 | -3.284 | -2.684 | -2.357 |
| 0.6 | -1.155 | -3.231 | -2.607 | -2.269 | -0.894 | -3.258 | -2.651 | -2.319 |
| 0.7 | -1.277 | -3.125 | -2.467 | -2.127 | -1.207 | -3.132 | -2.475 | -2.135 |
| 0.8 | **-2.398\*\*** | -3.033 | -2.380 | -2.033 | -1.014 | -3.023 | -2.370 | -2.023 |
| 0.9 | -1.540 | -2.756 | -2.085 | -1.725 | -1.179 | -2.693 | -2.021 | -1.661 |
| **Quantiles** | **FR BENCHMARK 10 YEAR DS GOVT. INDEX** | **UK BENCHMARK 10 YEAR DS GOVT. INDEX** |
| 0.1 | -0.889 | -2.744 | -2.072 | -1.712 | **-2.296\*\*** | -2.8768 | -2.2126 | -1.8555 |
| 0.2 | 0.039 | -2.986 | -2.335 | -1.985 | -1.747 | -3.1569 | -2.508 | -2.168 |
| 0.3 | -0.935 | -3.183 | -2.542 | -2.202 | -0.699 | -3.2435 | -2.6275 | -2.2922 |
| 0.4 | -0.927 | -3.298 | -2.698 | -2.377 | -0.962 | -3.2806 | -2.6806 | -2.3537 |
| 0.5 | -0.950 | -3.259 | -2.653 | -2.321 | 0.000 | -3.2914 | -2.6914 | -2.3675 |
| 0.6 | **-2.467\*\*** | -3.173 | -2.529 | -2.189 | -0.548 | -3.2066 | -2.5725 | -2.2325 |
| 0.7 | **-2.347\*** | -3.117 | -2.457 | -2.117 | 0.168 | -3.1097 | -2.4505 | -2.1097 |
| 0.8 | **-2.236\*\*** | -2.857 | -2.190 | -1.832 | 0.374 | -3.0064 | -2.3551 | -2.0064 |
| 0.9 | -1.658 | -2.721 | -2.049 | -1.689 | 1.134 | -2.7163 | -2.044 | -1.684 |

*3.4. Cryptocurrency market*

Our sample comprises the three main cryptocurrencies – Bitcoin, Ethereum and Litecoin. Table 1 reveals that interestingly for all these three cryptocurrencies, the worst impact of the pandemic is noticed on the same date - 12/03/2020, suggesting some kind of co-movement among the three inter-related markets. While all three cryptocurrencies lose more than half of their pre-pandemic highest values following the COVID, the highest decrease is observed for LTC (approx. 64%), while Bitcoin loses the least, 53%. Just as sharp as the reactions are the recovery rates for all the three cryptocurrencies with gains exceeding 50% over lowest values. While Ethereum tops the list with the highest recovery rate of 157.17%, Bitcoin shows the most sluggish recovery at only 151.74% of the pandemic bottom. Despite these high recovery rates, none of the three cryptocurrencies are able to achieve their pre-pandemic highest values in 2020.

As a group, cryptocurrencies exhibit one of the highest reactivity and recovery rates among the financial assets studied. Decline in values exceed 50% in all cases, and so do recovery rates. Cryptocurrencies as a group offer the highest recovery rate with the only exception of Rhodium with a gain of 175% over the pandemic bottom value. Despite these high recovery rates, values in April fail to catch up with pre-crisis values.

**Fig. 4. Losses and gains in the prices of the selected cryptocurrencies, sorted by losses, %.**

The losses represent the pandemic bottom value relatively the maximum values in 2020. Gains are the increases relatively to the pandemic bottom values.

Results of the quantile unit root tests for cryptocurrencies are presented in Table 5 (Table A8 contains the Koenker & Xiao (2004) test results for comparison). For the Bitcoin, using the Yang and Zhao (2020) tests, we fail to reject the null of unit root for higher quantiles studied (>3). This implies a very high degree of persistence. Results using Koenker and Xiao (2004) offer the similar pattern. We observe the potential for mean reversion only in lower quantiles of the shock (up to 0.3), while for all other quantiles, the return series depicts a very high persistence, suggesting long-term memory behaviour. Ethereum and Litecoin display roughly the similar pattern with mean reversion only in the lowest quantiles. This suggests the inability of them to revert to normal values at very high levels of shock.

**Table 5 Tests for quantile unit root, cryptocurrencies**

Table shows the results of the quantile nonlinear unit root tests with covariates, *tkss*, estimated as in Yang and Zhao (2020). The asymptotic critical values are calculated with significance at the 1%, 5% and 10% levels. The null hypothesis of the presence of a unit root is rejected if the calculated test statistic is lower in value than calculated critical asymptotic values at the 1%(\*\*\*), 5%(\*\*) and 10%(\*) levels of significance. Statistically significant values of *YZtks* are highlighted in bold, while the respective asymptotic critical values that indicate a significance level are underlined.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Quantiles** | ***YZtks*** | **asymptotic critical values** | ***YZtks*** | **asymptotic critical values** |
| **1%** | **5%** | **10%** | **1%** | **5%** | **10%** |
| **BTC** | **ETH** |
| 0.1 | **-4.176\*\*\*** | -2.643 | -1.969 | -1.609 | **-2.99\*\*\*** | -2.562 | -1.887 | -1.527 |
| 0.2 | **-3.984\*\*\*** | -3.063 | -2.407 | -2.063 | **-3.025\*\*** | -3.151 | -2.500 | -2.160 |
| 0.3 | **-4.126\*\*\*** | -3.198 | -2.562 | -2.222 | -2.135 | -3.235 | -2.614 | -2.277 |
| 0.4 | -1.191 | -3.240 | -2.623 | -2.287 | 0.316 | -3.257 | -2.650 | -2.317 |
| 0.5 | 1.855 | -3.246 | -2.632 | -2.297 | 2.272 | -3.255 | -2.647 | -2.314 |
| 0.6 | 3.514 | -3.246 | -2.631 | -2.296 | 3.772 | -3.229 | -2.604 | -2.266 |
| 0.7 | 3.255 | -3.150 | -2.500 | -2.160 | 4.032 | -3.094 | -2.436 | -2.094 |
| 0.8 | 2.841 | -2.924 | -2.266 | -1.912 | 3.089 | -2.938 | -2.281 | -1.928 |
| 0.9 | 0.999 | -2.639 | -1.966 | -1.606 | 1.395 | -2.535 | -1.859 | -1.499 |
|  | **LTC** |
| 0.1 | **-2.784\*\*\*** | -2.557 | -1.881 | -1.521 |
| 0.2 | **-5.194\*\*\*** | -3.042 | -2.388 | -2.042 |
| 0.3 | **-2.539\*** | -3.223 | -2.595 | -2.255 |
| 0.4 | -1.933 | -3.257 | -2.650 | -2.317 |
| 0.5 | 0.493 | -3.259 | -2.653 | -2.321 |
| 0.6 | 2.632 | -3.214 | -2.583 | -2.243 |
| 0.7 | 3.603 | -3.099 | -2.440 | -2.099 |
| 0.8 | 3.322 | -2.894 | -2.232 | -1.876 |
| 0.9 | 2.081 | -2.468 | -1.790 | -1.430 |

As a group, cryptocurrencies seem to disappoint in terms of providing an assurance of bouncing back or recovery in very bad times, i.e. in periods of very high external shocks. This makes this asset class highly risky in the long run in terms of unpredictability of returns, but on the other hand, more efficient, making our results in line with Urquhart (2016) and Wei (2018) who document increasing efficiency over time for the Bitcoin. Our results are also consistent with Caporale et al. (2018) with regard to general persistence in the cryptocurrency market. Our results also support the results of Philippe et al. (2018) and Turatti et al. (2020) in terms of mean-aversion behaviour of the Bitcoin. Corbet and Katsiampa (2020) document that Bitcoin exhibits similar asymmetric reverting patterns for minutely, hourly, daily and weekly returns between June 2010 and February 2018. Evidence of mean reverting behavior also could indicate that losing cryptocurrency portfolios could theoretically outperform winning cryptocurrency portfolios (Nam et al., 2006; Corbet & Katsiampa, 2020).

 In short, our results raise questions as to the safe haven properties of the Bitcoin.

**4. Conclusion**

The impact of the COVID-19 crisis on financial markets cannot be understated. While almost no asset class has been spared from its panic, the varied patterns of reaction and recovery across various asset groups raise the important question of mean reversion. It becomes interesting to examine their potential of recovery to normal levels in extremely turbulent times such as the COVID, or simply evaluate their safe haven characteristics. This paper investigates the mean-reversion properties of four broad asset classes – equity indexes, 10-year government bonds, precious metals and the rather contemporary, cryptocurrencies. Using the Yang and Zhao (2020) quantile nonlinear unit root test to test for persistence enables us to identify unit root processes across different quantiles of shock. To check our results, we also use the quantile test of Koenker and Xiao (2004). The received empirical results show the incremental power of the Yang and Zhao (2020) approach over the of Koenker and Xiao (2004).

The results show significant diversity in the reaction and recovery patterns across selected asset classes. Almost all equity indices demonstrate high potential for recovery even in very high periods of shock, reiterating their safe haven characteristics. Among precious metals, gold, platinum, silver and rhodium exhibit mean-reverting behavior only in the lower quantiles of the shock, as against palladium and GSCI which do not demonstrate mean reversion. Our findings are consistent with Gil-Alana et al. (2015), Lucey and Li (2015), among others. For bond markets, we find that German bonds experience the sharpest fall in value and the poorest recovery after the pandemic bottom day. US bonds not only react less negatively to the shock, but also end up reaching their highest 2020 value post-COVID. As a group, government bonds display high persistence.

As a group, cryptocurrencies exhibit one of the highest reactivity and recovery rates among the financial assets studied. While this may seem encouraging, our quantile unit root tests suggest otherwise. Our results reveal that Bitcoin, Ethereum and Litecoin offer for post-shock recovery towards long-term equilibrium only in lower levels of shock. This raises questions as to the ‘safe haven’ characteristics of them. Our analysis indicates that as a group, cryptocurrencies represent the riskiest asset class in the long-run in terms of unpredictability of returns.

Our results can be useful to investors to enable them to make more informed portfolio decisions to control downside risk in the wake of extreme events. Our findings provide novel empirical evidence on reaction and recovery patterns for different asset classes, contributing to sub-streams of literature in market efficiency, safe havens, and of course, the wave of recent papers on the quantification of the financial effects of the COVID-19 pandemic. Our results also benefit financial regulators in the areas of monetary policy. This work can help foster a better understanding of mean reversion for financial markets as a whole and its predictability. A useful addition could be the examination of the speed of mean reversion in terms of half-lives, for example, something we leave for future research.

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**Appendix**

**Table A.1 Descriptive statistics of the close prices of the selected precious metals (data source: Thomson EIKON)**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | min | max | median | mean | SE.mean | CI.mean 0.95 | var | std.dev |
| Gold, Handy & Harman Base $/Troy Oz | 1178.400 | 2067.150 | 1503.100 | 1539.228 | 8.757 | 17.189 | 63574.678 | 252.140 |
| Platinum,Free Market $/troy oz | 586.600 | 1300.500 | 875.700 | 912.798 | 4.502 | 8.837 | 16802.896 | 129.626 |
| Silver, Handy&Harman (NY) U$/Troy OZ | 12.130 | 28.990 | 17.030 | 18.886 | 0.161 | 0.315 | 21.391 | 4.625 |
| Palladium U$/Troy Ounce | 849.000 | 3000.000 | 1768.000 | 1786.150 | 19.953 | 39.164 | 330029.278 | 574.482 |
| Rhodium CIF NWE U$/Ounce | 54321.000 | 809447.000 | 171615.000 | 247194.240 | 7304.741 | 14337.989 | 44234815441.965 | 210320.744 |
| Osmium (Euro) E/KG | 10389.000 | 12010.000 | 11420.000 | 11390.207 | 12.603 | 24.756 | 85926.850 | 293.133 |
| S&P GSCI Precious Metal Tot. Ret. - RETURN IND. (OFCL) | 1403.280 | 2407.610 | 1772.640 | 1805.258 | 9.693 | 19.026 | 77886.125 | 279.081 |
| Iridium U$/Troy Oz | 1040.000 | 6300.000 | 1480.000 | 2061.230 | 48.895 | 95.972 | 1981882.723 | 1407.794 |
| Ruthenium CIF NWE U$/Ounce | 223.000 | 798.000 | 268.000 | 285.636 | 3.243 | 6.365 | 8717.577 | 93.368 |

**Table A.2 Descriptive statistics of the close prices of the selected bonds (data source: Thomson EIKON)**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | min | max | median | mean | SE.mean | CI.mean.0.95 | var | std.dev |
| BD BENCHMARK 10 YEAR DS GOVT. INDEX  | 170.848 | 199.977 | 189.548 | 186.973 | 0.255 | 0.500 | 53.873 | 7.340 |
| FR BENCHMARK 10 YEAR DS GOVT. INDEX  | 205.709 | 235.330 | 224.883 | 221.944 | 0.295 | 0.578 | 71.904 | 8.480 |
| UK BENCHMARK 10 YEAR DS GOVT. INDEX  | 193.678 | 224.660 | 210.819 | 210.521 | 0.308 | 0.605 | 78.843 | 8.879 |
| US BENCHMARK 10 YEAR DS GOVT. INDEX  | 137.505 | 179.202 | 157.698 | 158.161 | 0.458 | 0.898 | 173.665 | 13.178 |

**Table A.3 Descriptive statistics of the close prices of the selected indexes (data source: Thomson EIKON)**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | min | max | median | mean | SE.mean | CI.mean.0.95 | var | std.dev |
| S&P 500 COMPOSITE  | 2237.400 | 4255.150 | 2976.740 | 3134.306 | 15.824 | 31.060 | 207578.654 | 455.608 |
| DAX 30 | 8441.710 | 15729.520 | 12526.720 | 12562.987 | 43.901 | 86.171 | 1597756.470 | 1264.024 |
| DOW JONES COMPOSITE 65 STOCK AVE  | 6100.310 | 11738.220 | 8774.090 | 9012.327 | 34.908 | 68.519 | 1010196.919 | 1005.086 |
| DOW JONES INDUSTRIALS | 18591.930 | 34777.760 | 26492.210 | 27181.654 | 101.895 | 200.004 | 8607250.583 | 2933.812 |
| EURO STOXX  | 261.534 | 459.798 | 377.464 | 376.756 | 1.148 | 2.253 | 1091.968 | 33.045 |
| EURO STOXX 50  | 2385.823 | 4158.137 | 3432.536 | 3426.287 | 10.348 | 20.311 | 88769.906 | 297.943 |
| FRANCE CAC 40  | 3754.840 | 6666.260 | 5426.410 | 5383.664 | 17.397 | 34.148 | 250903.330 | 500.903 |
| FTSE 100 | 4993.890 | 7877.450 | 7088.180 | 6915.715 | 21.271 | 41.751 | 375082.154 | 612.440 |
| FTSE 250  | 12829.700 | 22933.290 | 19666.520 | 19516.244 | 62.763 | 123.192 | 3265545.295 | 1807.082 |
| ISRAEL TA 125 | 1105.950 | 1783.210 | 1459.580 | 1481.907 | 4.251 | 8.344 | 14980.940 | 122.397 |
| IBEX 35 | 6107.200 | 10271.400 | 9030.600 | 8657.644 | 34.679 | 68.069 | 996993.172 | 998.495 |
| NASDAQ 100  | 5899.350 | 14163.810 | 8006.120 | 9185.338 | 82.096 | 161.140 | 5587211.983 | 2363.728 |
| NASDAQ COMPOSITE | 9.630 | 8164.000 | 46.320 | 2790.281 | 125.937 | 247.193 | 13148030.794 | 3626.021 |
| NIKKEI 225 STOCK AVERAGE  | 16552.830 | 30467.750 | 22532.080 | 23219.999 | 98.762 | 193.854 | 8086030.177 | 2843.595 |
| PORTUGAL PSI-20 | 3596.080 | 5787.440 | 5029.680 | 4938.388 | 15.556 | 30.534 | 200606.907 | 447.892 |

**Table A.4 Descriptive statistics of the close prices of the selected cryptocurrencies (data source: http://www.cryptodatadownload.com/)**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | min | max | median | mean | SE.mean | CI.mean.0.95 | var | std.dev |
| BTCUSD | 3256 | 63438 | 8859 | 14131.35659 | 422.8695495 | 829.674769 | 207608459.4 | 14408.62448 |
| ETHUSD | 84.6 | 4215 | 236.843 | 537.1962059 | 20.79299315 | 40.7960843 | 501956.6828 | 708.4890139 |
| LTCUSD | 23.44 | 389.175 | 60.759 | 86.21838674 | 1.744220641 | 3.422180337 | 3532.116853 | 59.43161493 |

**Koenker and Xiao (2004) test results**

**Table A5 Tests for quantile unit root, precious metals**

Table shows the results of the quantile nonlinear unit root tests with covariates, *Ztkss*, estimated as in Koenker and Xiao (2004). The asymptotic critical values are calculated with significance at the 1%, 5% and 10% levels. The null hypothesis of the presence of a unit root is rejected if the calculated test statistic is lower in value than calculated critical values at the 1%, 5% and 10% levels of significance.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Quantiles** | ***tks*** | **asymptotic critical values** | ***tks*** | **asymptotic critical values** |
| **1%** | **5%** | **10%** | **1%** | **5%** | **10%** |
| **Gold** | **Platinum** |
| 0.1 | **-4.649** | -3.080 | -2.425 | -2.083 | **-3.355** | -3.102 | -2.456 | -2.115 |
| 0.2 | **-2.345** | -3.138 | -2.508 | -2.169 | **-3.481** | -3.135 | -2.503 | -2.164 |
| 0.3 | -1.722 | -3.166 | -2.548 | -2.213 | **-2.745** | -3.165 | -2.546 | -2.211 |
| 0.4 | -0.146 | -3.231 | -2.627 | -2.301 | **-2.640** | -3.193 | -2.586 | -2.254 |
| 0.5 | 0.831 | -3.171 | -2.555 | -2.220 | -0.256 | -3.183 | -2.572 | -2.239 |
| 0.6 | 1.354 | -3.170 | -2.553 | -2.219 | 0.092 | -3.156 | -2.533 | -2.196 |
| 0.7 | 2.907 | -3.162 | -2.542 | -2.206 | 0.242 | -3.163 | -2.543 | -2.207 |
| 0.8 | 2.904 | -3.187 | -2.578 | -2.245 | 0.232 | -3.126 | -2.490 | -2.151 |
| 0.9 | 3.323 | -3.135 | -2.504 | -2.165 | -0.663 | -3.043 | -2.383 | -2.038 |
|   | **Silver** | **Palladium** |
| 0.1 | **-3.462\*\*\*** | -3.118 | -2.479 | -2.139 | -1.739 | -3.106 | -2.462 | -2.122 |
| 0.2 | **-3.019\*\*** | -3.143 | -2.515 | -2.176 | -1.419 | -3.128 | -2.493 | -2.154 |
| 0.3 | **-2.479\*\*** | -3.136 | -2.504 | -2.165 | -1.414 | -3.129 | -2.495 | -2.155 |
| 0.4 | -0.578 | -3.105 | -2.460 | -2.120 | -0.988 | -3.132 | -2.499 | -2.159 |
| 0.5 | 0.859 | -3.108 | -2.464 | -2.124 | -0.861 | -3.129 | -2.494 | -2.155 |
| 0.6 | 1.906 | -3.125 | -2.489 | -2.149 | -0.603 | -3.092 | -2.441 | -2.100 |
| 0.7 | 3.096 | -3.096 | -2.447 | -2.106 | -0.001 | -3.116 | -2.475 | -2.136 |
| 0.8 | 3.273 | -3.113 | -2.472 | -2.132 | 0.225 | -3.076 | -2.419 | -2.077 |
| 0.9 | 3.023 | -3.109 | -2.465 | -2.125 | 0.693 | -3.041 | -2.382 | -2.037 |
|  | **Rhodium** | **Osmium** |
| 0.1 | **-4.645\*\*\*** | -2.888 | -2.246 | -1.884 | -1.099 | -3.106 | -2.462 | -2.122 |
| 0.2 | **-4.457\*\*\*** | -2.883 | -2.241 | -1.878 | -0.531 | -3.178 | -2.565 | -2.231 |
| 0.3 | **-2.853\*\*** | -2.891 | -2.251 | -1.889 | -1.306 | -3.209 | -2.602 | -2.273 |
| 0.4 | **-2.207\*** | -2.902 | -2.264 | -1.902 | -1.984 | -3.192 | -2.585 | -2.253 |
| 0.5 | 0.278 | -2.911 | -2.276 | -1.914 | **-2.513** | -3.191 | -2.584 | **-2.252** |
| 0.6 | 2.173 | -2.913 | -2.278 | -1.916 | **-2.968** | -3.183 | **-2.572** | -2.239 |
| 0.7 | 3.752 | -2.943 | -2.303 | -1.945 | **-3.318** | -3.173 | -2.558 | -2.223 |
| 0.8 | 2.914 | -2.980 | -2.333 | -1.980 | **-2.879** | -3.143 | **-2.515** | -2.177 |
| 0.9 | 2.891 | -2.992 | -2.342 | -1.991 | -1.318 | -3.065 | -2.403 | -2.061 |
|   | **Iridium** | **GSCI** |
| 0.1 | **-4.175\*\*\*** | -3.063 | -2.400 | -2.058 | 0.000 | -2.784 | -2.116 | -1.753 |
| 0.2 | **-3.648\*\*\*** | -3.094 | -2.445 | -2.104 | 0.000 | -2.784 | -2.116 | -1.753 |
| 0.3 | -1.453 | -3.098 | -2.450 | -2.110 | 0.000 | -2.784 | -2.116 | -1.753 |
| 0.4 | 0.207 | -3.124 | -2.487 | -2.148 | 0.000 | -2.826 | -2.168 | -1.805 |
| 0.5 | 0.177 | -3.092 | -2.442 | -2.101 | 0.000 | -2.914 | -2.279 | -1.918 |
| 0.6 | 1.981 | -3.099 | -2.451 | -2.110 | 0.000 | -2.784 | -2.116 | -1.753 |
| 0.7 | 2.929 | -3.104 | -2.459 | -2.119 | 0.000 | -2.784 | -2.116 | -1.753 |
| 0.8 | 2.830 | -3.083 | -2.428 | -2.087 | 0.000 | -2.784 | -2.116 | -1.753 |
| 0.9 | 3.658 | -3.074 | -2.415 | -2.074 | 0.081 | -2.862 | -2.213 | -1.851 |
|   | **Ruthenium** |
| 0.1 | 0.000 | -2.784 | -2.116 | -1.753 |
| 0.2 | 0.000 | -2.784 | -2.116 | -1.753 |
| 0.3 | 0.000 | -2.784 | -2.116 | -1.753 |
| 0.4 | 0.000 | -2.784 | -2.116 | -1.753 |
| 0.5 | 0.000 | -2.814 | -2.153 | -1.790 |
| 0.6 | 0.000 | -2.784 | -2.116 | -1.753 |
| 0.7 | 0.000 | -2.784 | -2.116 | -1.753 |
| 0.8 | 2.708 | -2.784 | -2.116 | -1.753 |
| 0.9 | 6.555 | -2.784 | -2.116 | -1.753 |

**Table A6 Tests for quantile unit root, stock indexes**

Table shows the results of the quantile nonlinear unit root tests with covariates, *tkss*, estimated as in Koenker and Xiao (2004). The asymptotic critical values are calculated with significance at the 1%, 5% and 10% levels. The null hypothesis of the presence of a unit root is rejected if the calculated test statistic is lower in value than calculated critical values at the 1%, 5% and 10% levels of significance. Statistically significant values of YZtks are highlighted in bold.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Quantiles** | ***tks*** | **asymptotic critical values** | ***tks*** | **asymptotic critical values** |
| **1%** | **5%** | **10%** | **1%** | **5%** | **10%** |
| **S&P500** | **DAX30** |
| 0.1 | 0.066 | -3.139 | -2.510 | -2.171 | 3.410 | -3.110 | -2.468 | -2.128 |
| 0.2 | 0.106 | -3.151 | -2.527 | -2.190 | 1.761 | -3.138 | -2.508 | -2.169 |
| 0.3 | -0.470 | -3.111 | -2.469 | -2.129 | 0.514 | -3.132 | -2.500 | -2.160 |
| 0.4 | -0.955 | -3.145 | -2.518 | -2.180 | 0.126 | -3.126 | -2.490 | -2.150 |
| 0.5 | -0.770 | -3.155 | -2.532 | -2.195 | -1.401 | -3.114 | -2.473 | -2.133 |
| 0.6 | -0.558 | -3.143 | -2.515 | -2.177 | **-2.167** | -3.101 | -2.455 | -2.114 |
| 0.7 | -0.747 | -3.118 | -2.479 | -2.139 | **-4.191** | -3.107 | -2.463 | -2.123 |
| 0.8 | -0.763 | -3.080 | -2.424 | -2.082 | **-5.379** | -3.077 | -2.421 | -2.079 |
| 0.9 | **-1.271** | -2.911 | -2.275 | -1.914 | **-2.813** | -2.995 | -2.345 | -1.994 |
|   | **DJ65** | **DJIndustr** |
| 0.1 | 0.992 | -3.111 | -2.469 | -2.129 | 1.680 | -3.082 | -2.427 | -2.086 |
| 0.2 | 0.654 | -3.118 | -2.478 | -2.138 | 0.261 | -3.130 | -2.496 | -2.157 |
| 0.3 | 0.266 | -3.165 | -2.547 | -2.211 | -0.188 | -3.158 | -2.536 | -2.200 |
| 0.4 | -1.080 | -3.138 | -2.507 | -2.168 | -0.747 | -3.145 | -2.518 | -2.180 |
| 0.5 | -1.467 | -3.117 | -2.478 | -2.138 | -1.836 | -3.142 | -2.513 | -2.175 |
| 0.6 | **-3.050** | -3.120 | -2.482 | -2.143 | **-2.897** | -3.139 | -2.509 | -2.170 |
| 0.7 | **-3.235** | -3.105 | -2.460 | -2.120 | **-3.075** | -3.122 | -2.485 | -2.146 |
| 0.8 | **-4.209** | -3.043 | -2.384 | -2.039 | **-3.329** | -3.081 | -2.426 | -2.085 |
| 0.9 | -1.912 | -2.874 | -2.229 | -1.867 | **-2.116** | -2.888 | -2.246 | -1.884 |
|  | **EuroStoxx** | **EuroStoxx50** |
| 0.1 | 2.968 | -3.072 | -2.413 | -2.071 | 2.793 | -3.094 | -2.445 | -2.104 |
| 0.2 | 2.241 | -3.126 | -2.490 | -2.151 | 1.988 | -3.151 | -2.527 | -2.190 |
| 0.3 | 1.690 | -3.127 | -2.491 | -2.152 | 1.376 | -3.124 | -2.488 | -2.148 |
| 0.4 | 0.501 | -3.126 | -2.491 | -2.151 | 0.533 | -3.123 | -2.486 | -2.147 |
| 0.5 | -0.739 | -3.121 | -2.483 | -2.143 | -1.148 | -3.114 | -2.473 | -2.133 |
| 0.6 | **-2.483** | -3.099 | -2.451 | -2.111 | **-2.357** | -3.099 | -2.451 | -2.110 |
| 0.7 | **-3.690** | -3.071 | -2.411 | -2.069 | **-3.529** | -3.078 | -2.421 | -2.079 |
| 0.8 | **-5.027** | -3.039 | -2.380 | -2.035 | **-4.882** | -3.034 | -2.376 | -2.030 |
| 0.9 | **-5.207** | -2.923 | -2.286 | -1.926 | **-5.089** | -2.918 | -2.282 | -1.921 |
|   | **CAC40** | **FTSE100** |
| 0.1 | 3.556 | -3.107 | -2.464 | -2.123 | 3.639 | -3.127 | -2.492 | -2.152 |
| 0.2 | 3.011 | -3.113 | -2.472 | -2.132 | 2.481 | -3.143 | -2.515 | -2.177 |
| 0.3 | 2.361 | -3.120 | -2.482 | -2.142 | 1.452 | -3.150 | -2.525 | -2.188 |
| 0.4 | 2.338 | -3.126 | -2.491 | -2.151 | -0.099 | -3.139 | -2.509 | -2.170 |
| 0.5 | 0.360 | -3.120 | -2.482 | -2.142 | -1.040 | -3.117 | -2.477 | -2.137 |
| 0.6 | **-2.501** | -3.097 | -2.449 | -2.108 | **-3.262** | -3.102 | -2.457 | -2.116 |
| 0.7 | **-3.603** | -3.075 | -2.418 | -2.076 | **-6.352** | -3.092 | -2.441 | -2.100 |
| 0.8 | **-4.353** | -3.082 | -2.427 | -2.085 | **-7.456** | -3.034 | -2.376 | -2.030 |
| 0.9 | **-6.346** | -2.916 | -2.280 | -1.919 | **-9.469** | -2.913 | -2.278 | -1.916 |
|   | **FTSE250** | **Israel TA125** |
| 0.1 | 4.410 | -3.017 | -2.362 | -2.014 | 1.215 | -3.216 | -2.610 | -2.282 |
| 0.2 | 3.834 | -3.112 | -2.470 | -2.129 | 1.276 | -3.153 | -2.529 | -2.192 |
| 0.3 | 1.655 | -3.114 | -2.474 | -2.134 | 0.344 | -3.166 | -2.548 | -2.212 |
| 0.4 | 0.517 | -3.134 | -2.502 | -2.163 | -1.373 | -3.157 | -2.535 | -2.199 |
| 0.5 | -0.859 | -3.119 | -2.481 | -2.141 | -0.556 | -3.146 | -2.520 | -2.182 |
| 0.6 | **-4.138** | -3.095 | -2.446 | -2.105 | **-2.430** | -3.113 | -2.472 | -2.132 |
| 0.7 | **-5.484** | -3.074 | -2.415 | -2.074 | **-2.408** | -3.058 | -2.396 | -2.053 |
| 0.8 | **-6.023** | -3.025 | -2.369 | -2.021 | **-2.686** | -3.090 | -2.439 | -2.097 |
| 0.9 | **-6.720** | -2.923 | -2.286 | -1.926 | **-3.582** | -2.957 | -2.314 | -1.958 |
|  | **IBEX35** | **NASDAQ100** |
| 0.1 | 4.693 | -3.077 | -2.420 | -2.079 | -0.976 | -3.134 | -2.501 | -2.162 |
| 0.2 | 4.083 | -3.139 | -2.509 | -2.170 | -0.545 | -3.186 | -2.577 | -2.244 |
| 0.3 | 2.334 | -3.143 | -2.515 | -2.176 | -0.885 | -3.196 | -2.589 | -2.257 |
| 0.4 | -0.016 | -3.141 | -2.512 | -2.173 | -0.404 | -3.190 | -2.583 | -2.250 |
| 0.5 | -1.875 | -3.136 | -2.505 | -2.166 | 0.530 | -3.183 | -2.572 | -2.239 |
| 0.6 | **-4.115** | -3.132 | -2.499 | -2.159 | 0.949 | -3.164 | -2.545 | -2.210 |
| 0.7 | **-5.698** | -3.109 | -2.466 | -2.125 | 2.260 | -3.145 | -2.517 | -2.179 |
| 0.8 | **-7.573** | -3.074 | -2.416 | -2.074 | 1.657 | -3.054 | -2.392 | -2.049 |
| 0.9 | **-7.019** | -3.006 | -2.353 | -2.004 | 1.022 | -2.933 | -2.294 | -1.935 |
|   | **NIKKEI.225** | **PSI20** |
| 0.1 | 0.956 | -3.163 | -2.544 | -2.208 | 3.244 | -3.084 | -2.430 | -2.089 |
| 0.2 | 0.560 | -3.158 | -2.537 | -2.200 | 3.412 | -3.138 | -2.507 | -2.169 |
| 0.3 | -0.423 | -3.170 | -2.553 | -2.218 | 2.753 | -3.157 | -2.535 | -2.198 |
| 0.4 | -0.977 | -3.144 | -2.516 | -2.178 | 0.104 | -3.163 | -2.544 | -2.208 |
| 0.5 | 0.000 | -3.130 | -2.496 | -2.156 | -1.229 | -3.172 | -2.556 | -2.222 |
| 0.6 | -0.397 | -3.161 | -2.540 | -2.204 | **-4.452** | -3.154 | -2.531 | -2.194 |
| 0.7 | -1.106 | -3.159 | -2.537 | -2.201 | **-5.622** | -3.129 | -2.495 | -2.155 |
| 0.8 | -1.364 | -3.132 | -2.499 | -2.159 | **-6.055** | -3.084 | -2.430 | -2.089 |
| 0.9 | -1.495 | -3.086 | -2.433 | -2.091 | **-6.869** | -2.967 | -2.322 | -1.967 |
|   | **NASDAQ** **COMPOSITE** |
| 0.1 | 5.679 | -2.784 | -2.116 | -1.753 |
| 0.2 | 4.897 | -2.784 | -2.116 | -1.753 |
| 0.3 | 3.599 | -2.784 | -2.116 | -1.753 |
| 0.4 | 1.336 | -2.784 | -2.116 | -1.753 |
| 0.5 | -0.699 | -2.784 | -2.116 | -1.753 |
| 0.6 | **-3.445** | -2.784 | -2.116 | -1.753 |
| 0.7 | **-4.237** | -2.784 | -2.116 | -1.753 |
| 0.8 | **-5.827** | -2.784 | -2.116 | -1.753 |
| 0.9 | **-7.324** | -2.784 | -2.116 | -1.753 |

**Table A7 Tests for quantile unit root, government bonds.**

Table shows the results of the quantile nonlinear unit root tests with covariates, *tkss*, estimated as in Koenker and Xiao (2004). The asymptotic critical values are calculated with significance at the 1%, 5% and 10% levels. The null hypothesis of the presence of a unit root is rejected if the calculated test statistic is lower in value than calculated critical values at the 1%, 5% and 10% levels of significance. Statistically significant values of YZtks are highlighted in bold.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Quantiles** | ***tks*** | **asymptotic critical values** | ***tks*** | **asymptotic critical values** |
| **1%** | **5%** | **10%** | **1%** | **5%** | **10%** |
| **BD BENCHMARK 10 YEAR DS GOVT. INDEX** | **US BENCHMARK 10 YEAR DS GOVT. INDEX**  |
| 0.1 | -1.154 | -3.143 | -2.514 | -2.176 | **-2.464** | -3.122 | -2.485 | -2.145 |
| 0.2 | -1.527 | -3.223 | -2.618 | -2.291 | -1.364 | -3.169 | -2.552 | -2.217 |
| 0.3 | -1.353 | -3.215 | -2.610 | -2.282 | -1.011 | -3.185 | -2.575 | -2.243 |
| 0.4 | -1.811 | -3.202 | -2.595 | -2.265 | -0.095 | -3.197 | -2.590 | -2.258 |
| 0.5 | -1.353 | -3.170 | -2.554 | -2.219 | -0.050 | -3.206 | -2.599 | -2.269 |
| 0.6 | -0.151 | -3.164 | -2.545 | -2.209 | -0.400 | -3.179 | -2.567 | -2.233 |
| 0.7 | 0.223 | -3.160 | -2.538 | -2.202 | -0.532 | -3.152 | -2.527 | -2.190 |
| 0.8 | -1.420 | -3.150 | -2.524 | -2.187 | -0.722 | -3.142 | -2.514 | -2.175 |
| 0.9 | -1.511 | -3.084 | -2.429 | -2.088 | -1.238 | -3.042 | -2.383 | -2.038 |
|   | **FR BENCHMARK 10 YEAR DS GOVT. INDEX** | **UK BENCHMARK 10 YEAR DS GOVT. INDEX** |
| 0.1 | -1.599 | -3.181 | -2.569 | -2.235 | **-2.493** | -3.121 | -2.484 | -2.144 |
| 0.2 | -0.381 | -3.180 | -2.568 | -2.234 | -1.919 | -3.145 | -2.518 | -2.180 |
| 0.3 | -0.842 | -3.216 | -2.610 | -2.282 | -0.599 | -3.169 | -2.552 | -2.217 |
| 0.4 | -0.319 | -3.220 | -2.615 | -2.287 | -0.873 | -3.184 | -2.573 | -2.240 |
| 0.5 | -0.523 | -3.176 | -2.562 | -2.228 | 0.000 | -3.190 | -2.582 | -2.249 |
| 0.6 | -1.254 | -3.145 | -2.517 | -2.179 | -0.410 | -3.186 | -2.576 | -2.244 |
| 0.7 | -1.259 | -3.150 | -2.525 | -2.187 | 0.475 | -3.175 | -2.560 | -2.226 |
| 0.8 | **-2.192** | -3.090 | -2.439 | -2.098 | 0.649 | -3.164 | -2.545 | -2.209 |
| 0.9 | -1.263 | -3.059 | -2.396 | -2.054 | 0.26 | -3.074 | -2.416 | -2.074 |

**Table A8 Tests for quantile unit root, cryptocurrencies.**

Table shows the results of the quantile nonlinear unit root tests with covariates, *tkss*, estimated as in Koenker and Xiao (2004). The asymptotic critical values are calculated with significance at the 1%, 5% and 10% levels. The null hypothesis of the presence of a unit root is rejected if the calculated test statistic is lower in value than calculated critical values at the 1%, 5% and 10% levels of significance. Statistically significant values of YZtks are highlighted in bold.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Quantiles** | ***tks~~s~~*** | **asymptotic critical values** | ***tks~~s~~*** | **asymptotic critical values** |
| **1%** | **5%** | **10%** | **1%** | **5%** | **10%** |
| **BTC** | **ETH** |
| 0.1 | **-3.419** | -3.103 | -2.457 | -2.117 | -1.876 | -3.126 | -2.491 | -2.151 |
| 0.2 | **-3.879** | -3.151 | -2.526 | -2.189 | **-2.759** | -3.163 | -2.543 | -2.208 |
| 0.3 | **-4.100** | -3.166 | -2.547 | -2.212 | -1.932 | -3.172 | -2.556 | -2.221 |
| 0.4 | -1.206 | -3.156 | -2.533 | -2.196 | 0.215 | -3.167 | -2.550 | -2.214 |
| 0.5 | 2.089 | -3.164 | -2.545 | -2.210 | 1.803 | -3.162 | -2.541 | -2.205 |
| 0.6 | 3.877 | -3.184 | -2.573 | -2.240 | 3.114 | -3.171 | -2.555 | -2.220 |
| 0.7 | 4.415 | -3.168 | -2.551 | -2.216 | 3.845 | -3.146 | -2.519 | -2.181 |
| 0.8 | 3.186 | -3.140 | -2.511 | -2.172 | 3.148 | -3.133 | -2.501 | -2.161 |
| 0.9 | 1.651 | -3.085 | -2.432 | -2.091 | 2.261 | -3.058 | -2.395 | -2.052 |
|   | **LTC** |
| 0.1 | **-3.297** | -3.108 | -2.464 | -2.124 |
| 0.2 | **-4.949** | -3.146 | -2.519 | -2.181 |
| 0.3 | **-3.636** | -3.172 | -2.556 | -2.221 |
| 0.4 | -1.667 | -3.168 | -2.551 | -2.215 |
| 0.5 | -0.356 | -3.172 | -2.556 | -2.221 |
| 0.6 | 1.012 | -3.161 | -2.541 | -2.205 |
| 0.7 | 3.891 | -3.146 | -2.519 | -2.181 |
| 0.8 | 3.659 | -3.116 | -2.476 | -2.136 |
| 0.9 | 2.877 | -3.036 | -2.378 | -2.032 |

1. The diverse financial effects of the pandemic have been considered by Corbet et al. (2020a), Goodell (2020), Sharif et al. (2020), and Yarovaya et al. (2020a, b) among others. [↑](#footnote-ref-1)