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RESEARCH ARTICLE

Analysis of the Frequency-Based Relationship between Inflation Expectations and Gold Returns in Turkey

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Abstract

This paper explores the relationship between inflation expectations and gold returns of monthly and annual maturities in Turkey from 2006 to 2020 with 177 monthly observations through the application of wavelet cohesion and causality tests. The findings reveal significantly negative cohesion in the short term and significantly positive cohesion in the long term, indicating that the hedging ability of gold prices exists only in the long term during crisis periods. Therefore, the findings provide evidence for the validity of the expected inflation effect hypothesis in Turkey. The ordinary least squares results, on the other hand, show that the ongoing COVID-19 pandemic is the most prominent factor in the movement of inflation and gold at all wavelet scales for the two types of maturities. The continuous wavelet transformation based Granger-causality test provides little evidence for out-of-phase and unidirectional causality running from the inflation expectations to gold returns in the higher and medium frequency bands. Furthermore, the QQR results show an asymmetrical impact on each other—implying a hedging effectiveness of gold against inflation expectations—and reveal that its size and magnitude change significantly under different economic conditions and data frequencies. The results have significant implications for portfolio and risk management during normal market conditions as well as hedging and speculation activities during crises in short term and long term periods, respectively.

Keywords

Inflation expectations, Gold returns, Wavelet analysis, Causality, Quantile-on-quantile

Introduction

Inflation expectations have been a significant subject in academic literature and central banking since the 1970s. A precondition for the success of the Central Bank of the Republic of Turkey (CBRT), the main purpose of which is to achieve and maintain price stability, is to manage inflation expectations of various economic units. The expectations of economic units for an inflation increase in the future cause inflation to actually rise; therefore, the efforts of central banks to control inflation expectations are important in terms of price stability. In fact, it is argued that the direction of the inflation expectation directly contributes to the direction of the actual change in inflation. Several prominent methods exist for measuring inflation

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expectations such as: (i) conducting a questionnaire, (ii) measuring the difference between inflation-indexed and ordinary government bonds, and (iii) wage negotiations between employees and employers. Of these methods, the CBRT prefers the first approach to measure the inflation expectations through the survey of expectations, which has been conducted monthly since August 2001. It aims to follow the expectations of experts and decision-makers in the financial and real sectors about several macroeconomic variables.[1] The timeline of inflation expectations and realized inflation rates in Turkey is given in Figure **1**, which shows how well both rates matched during the sample period.. It is clear that although both inflation rates followed a similar path and converged from time to time, the realized inflation rates were found to be higher than the expected rate, and this difference reached its highest level during the recent crisis. In other words, the magnitude of difference between the realized (6.30% and 25.24%) and expected inflation rates (2.05% and 17.03%) increased considerably during the recent currency crisis in Turkey for monthly and annual frequencies, respectively. The estimates of monthly (annual) inflation expectations exceed 90 (28) times the realized inflation rates for 177 observations and, as expected, there exists a high (low) approximate rate (close to zero) for short-term than long-term inflation rates in Turkey.

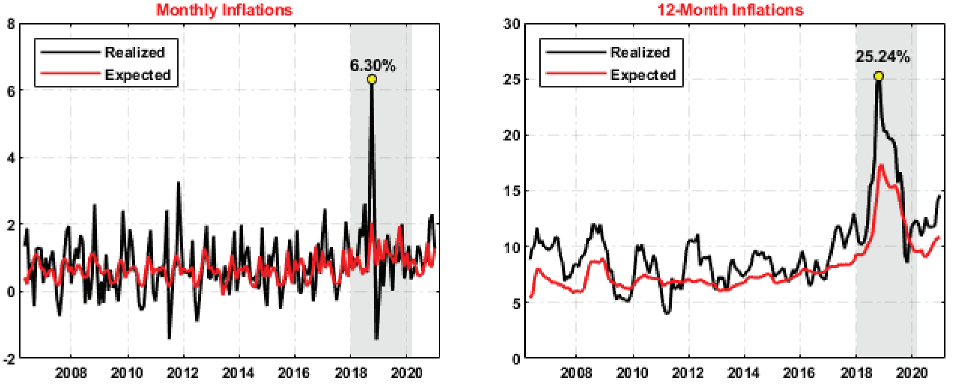

Figure 1. Monthly and Annual Inflation Rates in Turkey

On the one hand, the existing literature on the subject contains abundant information about the relationship of gold and ex-post inflation (see, for example, Kutan and Aksoy, 2004; Ranson and Wainright, 2005; Tiwari, 2011; Wang, Lee, & Thi, 2011; Conlon, Lucey, & Uddin, 2018, among others). Fisher's (1930) pioneering empirical study argued that expected nominal return of an asset could be seen as a combination of expected real return and inflation rate. In one of the earliest papers on this subject, Fama and Schwert (1977) examined the hedging effectiveness of certain investment assets against inflation and found that US government bonds and bills were excellent inflation-immunizing assets. Exploring gold as

1 It includes 32 questions to measure short and long term expectations on inflation (8 questions), interest rates (17 questions), exchange rates (3 questions), current account balance (2 questions), and growth expectations (2 questions).

an inflation hedge, Ghosh, Levin, Macmillan, & Wright (2004) divided the demand for gold into two categories as "asset demand" and "use demand". The first category, that is asset demand, reflects the widely maintained view that gold is held by governments, institutional investors, and individual investors as an investment tool since it is expected to provide an effective "hedge" against inflation, currency depreciation, and other forms of uncertainty. The second category, however, indicates direct use of gold in the production of jewelry, medals, coins, and electrical components, etc. Ghosh, et al. (2004), however, also noted that gold may constitute a safe haven for market participants in the long term, but it has significant price volatility in the short term. McCown and Zimmerman (2006) provided significant evidence for the hedging ability of gold and silver against inflation and reported that the two metals bore no market risk according to the estimates from the two leading theories: the capital asset pricing model (CAPM) and arbitrage pricing theory (APT). Worthington and Pahlavani (2007) argued that the reputation of gold was mainly driven by its durability, ease of transportability, universal acceptance, and easy authentication when compared to most other commodities. Although the demand for gold was greatly sensitive to cycles in business and uncertainty on economic activities (Baur and McDermott, 2010), the supply of gold was relatively stable and fixed because of its limited supply and production capacity (Garner, 1995; Beckmann and Czudaj, 2013). Proposing a new model of the gold standard, Faria and McAdam (2012) found that gold holdings and their prices increased over time as a function of population dynamics, but decreased with population growth rate.

On the other hand, the literature examining the relationship between gold and inflation expectations is relatively scarce and yields mixed results about the hedging effectiveness of gold prices against expected and unexpected inflation rates. A few studies such as Tkacz (2007), Le Long, De Ceuster, Annaert, & Amonhaemanon (2013), and Bampinas and Panagiotidis (2015), report a significantly positive association between the inflation expectations and gold prices, indicating the hedging ability of gold prices in the short term, the long term, or both. However, some studies also document insignificant results and report that gold prices are not useful in predicting future movements of inflation (Erb and Harvey, 2013; Tufail and Batool, 2013; Ghazali, Lean, & Bahari, 2015; Xu, Liu, Su, & Ortiz, 2019a). Among these studies, Blose (2010) has put forward two remarkable theories about the relationship between inflation expectations and gold. The first theory, or the expected inflation effect hypothesis, claims that the spot price of gold is highly dependent upon the changes in inflation expectations, implying that the level of expected inflation can be determined by following the changes in gold prices. Upward revisions in inflation expectations will lead to some investors purchasing gold with hedging or speculative investment motives, creating a sharp hike in gold prices simultaneously. The second theory reveals an important shortcoming of the first theory in that it ignores the effect of inflation on the interest rate and the cost of holding gold. Regardless of the source of financing, the effect of interest rates on the cost of investing in gold, whenever upward revisions in expected inflation take place, cannot be avoided. Hence, any speculative profit generated by the advantage of having better knowledge of expected inflation during inflationary periods would be offset by higher borrowing costs. Blose (2010) defines this phenomenon as the carrying cost hypothesis. According to this hypothesis, inflation expectations cannot be determined by current gold prices due to the uncorrelated association between the spot price of gold and future inflation expectations. By testing these hypotheses and following the suggestions of Kiviaho, Nikkinen, Piljak, & Rothovius (2014), the current study aims to bridge the gap related to the association between gold and expected inflation in Turkey. The novelty of the paper lies in the application of wavelet-based tests, correlation and causality, and nonlinear quantile regressions to gold-inflation expectations in Turkey at monthly and annual frequencies, and this documents significant positive/negative associations and unidirectional causal linkages intensifying around short and medium time horizons during crisis and non-crisis periods.

Through the application of wavelet cohesion and causality tests as well as a simple ordinary least squares (OLS) regression model, this paper explores the association between gold returns and inflation expectations of monthly and annual maturities in Turkey over the period of 2006 to 2020 with 177 monthly observations. The findings reveal significantly negative cohesion in the short term and significantly positive cohesion in the long term, indicating that the hedging ability of gold prices exists only in the long term during the crisis periods. Therefore, the findings provide evidence for the validity of the expected inflation effect hypothesis in Turkey. The OLS results, on the other hand, show that the ongoing Coronavirus disease (COVID-19) pandemic is the most prominent factor in the movement of inflation and gold at all wavelet scales for the two types of maturities, whereas the changes in credit default swap (CDS) spreads are an insignificant factor of the same. The continuous wavelet transformation (CWT)-based Granger-causality test provides little evidence for out-phase and unidirectional causal linkage from the inflation expectations to gold returns in the higher and medium frequency bands. Additionally, the results of QQR show both positive and negative impacts of expected inflation rates on gold returns across all quantiles, suggesting gold does not always act as a hedge instrument against inflation regardless of frequencies. The results yield significant implications for portfolio and risk management during normal market conditions as well as hedging and speculative activities during crises in short term and long term periods, respectively.

The study is presented as follows. We discuss the literature related to this study in Section 2. In the next section, we describe the methodology and give a brief description for each of the wavelet-based tests. The dataset of the present study is given in Section 4. The empirical findings and implications are detailed in Section 5. The last section concludes the study with final remarks.

Literature Review

Chua and Woodward (1982) used a simple regression model in their pioneering study to investigate the inflation hedging value of gold prices for six industrialized countries over the period of 1975 to 1980. The findings showed that both expected and unexpected inflation rates were significant positive factors in explaining gold returns in the USA, but insignificant in the other five countries of Canada, Germany, Japan, Switzerland, and the UK. Hence, investing in gold was found to be a useful hedging instrument against inflation for the short term investors in the USA. Sherman (1983), Moore (1990), and Garner (1995) obtained similar results. On the contrary, Mahdavi and Zhou (1997) and Kutan and Aksoy (2004) argued that short term volatilities in gold prices and improvement in financial futures markets had undermined the role of gold prices as a reliable leading indicator of inflation in the USA and Turkey, respectively.

Christie-David, Chaudhry, & Koch (2000) examined the effect of macroeconomic news releases on asset prices of silver, gold, and bond futures over the period of 1992 to 1995 using intraday data and employing robust nonparametric tests. The findings showed that the prices of gold futures strongly reacted to the announcement of consumer price index (CPI), gross domestic product (GDP), producer price index (PPI), and unemployment rate in a 15-minute period following the announcement, providing estimates of ex-post and ex-ante inflation rates.

Adrangi, Chatrath, & Raffiee (2003) investigated the relationship of real gold and silver returns with inflation rates through the application of co-integration tests. The findings revealed a significantly positive linkage between real gold returns and expected inflation in the USA and an insignificant effect of unexpected inflation rates on the gold returns. Furthermore, the empirical results put forward evidence supporting the Fisherian hypothesis, but not Fama's proxy hypothesis. In another noteworthy article, Tkacz (2007) examined gold prices as leading indicators for the future path of inflation rates in 14 countries at different time intervals, including 6, 12, 18, and 24 months, from 1994 to 2005. The results indicated that gold prices are useful leading indicators for predicting inflation rates of many developed countries with formal inflation targets up to two years in advance.

Hoang, Lahiani, & Heller (2016) provided robust evidence for the hedging ability of gold against inflation risk in the USA, the UK, and India in the short term; however, the findings failed to put forward any evidence for the existence of a long term association between the CPI and gold prices in China, India, and France because of traditional aspects of gold usage and customs control for gold trade in these countries.

Considering the unexpected changes in CPI as a measure of change in inflation expectations, Blose (2010) investigated the relationship of unexpected inflation rates with both gold and bond yields over a 20-year-period in the USA. The author presented a significantly positive impact of the changes in unexpected inflation rates on the changes in bond yields at time intervals of one, two, and three years, and further showed that this effect did not last for the two and three year maturities. On the other hand, the results yielded insufficient evidence against the null of the carrying cost hypothesis. This indicated an insignificant association between expected inflation and nominal gold returns during the examined period of 1988 to 2008 because the coefficients of the unexpected inflation rates are insignificantly different from zero. The author suggested investors to follow the changes in bond markets rather than the changes in gold prices for speculative purposes regarding inflation expectations. Xu et al. (2019a), on the other hand, tested the validity of both the expected inflation effect and the carrying cost hypotheses using a bootstrap causality test with a rolling window size of 60 months in the USA. The test results confirmed that the expected relation between gold returns and inflation was more steadily explained with the carrying cost hypothesis but not with the expected inflation effect hypothesis due to the existence of a negative relationship, indicating the hedging ability of gold exists only for certain periods.

Erb and Harvey (2013) examined the role of gold as a hedge or a safe haven against currency and unexpected inflation rates. The authors pointed out that during the period of 1975 to 2012, real gold prices were neither a safe haven nor a hedge against fluctuations in foreign exchange rates. Additionally, they found weak evidence that gold had been a useful hedging investment tool against unexpected inflation rates measured in both the short- and long-term. Furthermore, gold did not constitute a safe haven during highly inflationary periods in both developed and under-developed countries in the long term. The results of Sarac and Zeren (2014) contradicted previous findings since they found that gold was a useful hedging instrument against currency and inflation risks in Turkey. Additionally, Le Long et al. (2013) found that gold had acted as a hedge against both ex-post and ex-ante inflation in Vietnam and provided evidence in favor of the Fisher hypothesis given the oversensitivity of nominal gold returns for inflation rates during the period of January 2001 to December 2011. Similar results were obtained by Tufail and Batool (2013), finding that nominal gold returns, along with stocks and real estate, were immune to inflation rates (either expected or unexpected) in Pakistan over the period of 1960 to 2010. Conversely, the findings of Salisu, Raheem, & Ndako (2020) provided evidence against the Fisher hypothesis for investments in gold after considering asymmetry and structural breaks, suggesting equity and real estate investments instead of gold against inflation risk in the USA during periods of low or high market volatility.

Ghazali et al. (2015) examined the hedging ability of domestic gold prices against inflation, expected inflation, and unexpected inflation in Malaysia during the period of July 2001 to November 2011. The relationship between gold returns and all three forms of inflation was found to be negative, albeit not significant, indicating that gold is a poor hedging instrument in the short term domestically. Bampinas and Panagiotidis (2015) established that there was significant evidence in favor of the hedging ability of gold and silver against three measures of inflation rates—headline, expected, and core CPI—in the UK and the USA over the period of 1791 to 2010, with 220 annual observations. The findings related to the time-varying co-integration approach demonstrated that the long term relationship between gold and expected inflation became stronger and more stable from the late 1990s until 2008. Lucey et al. (2017) investigated the relationship of gold with both predicted and realized inflation in the UK, the USA, and Japan. The findings indicated evidence of a significant time-varying co-integration relationship between inflation measures and gold prices in all tested countries, and the study put forward evidence in favor of money supply in this relationship.

Using monthly spot and futures contracts of 12 maturities for the period of December 1979 to August 2016 and employing a nonparametric test of causality-in-quantiles, Balcilar, Ozdemir, Shahbaz, & Gunes (2018) studied the predictability of the effect of the mean and variance of gold price changes on inflation in G7 countries. The findings reported a unidirectional causality in mean and variance from the seasonally adjusted CPI to the changes in gold spot and futures prices in the middle quantiles ranging from t=0.20 to t=0.70. This indicated that gold did not hedge inflation risk during quiet or highly volatile periods in gold markets. Using the same approach, Shahzad, Mensi, Hammoudeh, Sohail, & Al-Yahyaee (2019) found significant asymmetric causal associations of the mean and variance between inflation and gold prices in China, France, Japan, and the UK for the mid-quantiles, validating the hedging effectiveness of gold in predicting inflation rates during normal economic conditions. The results of the QQ regression approach revealed a heterogeneous impact from inflation to gold returns through all quantiles within each economy and showed that the size and magnitude of inflation shocks had significant effect on the gold-inflation linkage. In a recent paper, Salisu, Ndako, & Oloko (2019) examined the hedging ability of gold and palladium against the inflation risks in member states of the Organization for Economic Co-operation and Development (OECD) and revealed that gold acted as an inflation hedge in 11 out of the 32 countries observed, suggesting extraordinary hedging capacity in Austria, Belgium, Canada, France, Italy, Korea, Luxembourg, and the USA, and partial hedging capacity in the Czech Republic, Slovakia, and Turkey. Sui, Rengifo, & Court (2021) concluded that the role of gold as a hedging instrument against exchange rate and inflation risks varied due to the volatility of gold prices and economic conditions, such as the level of inflation beyond a certain threshold in Turkey and Peru. Accounting for the effects of structural breaks in the price and return of gold, Xu, Su, & Ortiz (2019b) revealed that real gold returns were easily characterized by a nonlinear mean-reversion over investment horizons ranging from 1 month to 15 years, and thus, confirming that gold has been a reliable hedging instrument against inflation risk in the USA for the past four decades.

Utilizing the CWT approach, Conlon, et al. (2018) examined the hedging ability of gold, gold futures, and gold stocks on realized and unexpected inflation rates in Japan, Switzerland, the UK, and the USA over the sample period of January 1986 to December 2014 using monthly observations, yielding 564 total observations. The findings validated the hedging power of all gold instruments held at higher and medium frequencies, corresponding to 0.25 in 4 monthly periods, for realized inflation rates in all tested countries. Similar results were also obtained for unexpected inflation rates in the short and long term investment intervals only in the USA.

Huang, Jia, & Xu (2019) studied whether a threshold effect existed in the focal association between gold prices and market sentiment with inflation expectations over the period of February 2003 to December 2017 by employing a multivariate threshold regression model. The paper found that both inflation expectations and market sentiment exhibit a threshold effect on gold prices, indicating the impact of inflation expectations and financial market turbulence on the hedging ability of gold and its role as a safe haven. Further, it showed that the observed threshold effects varied between the pre-GFC (global financial crisis) and post-GFC (2007-2009) periods, implying that the threshold effects of inflation expectations were significant in both periods whereas the effects were insignificant to the market sentiment before the GFC. Gulseven and Ekici (2020) argued that the importance of gold and real estate as a hedge against inflation in Turkey increased in the absence of interest-earning assets, which were previously the best hedging instrument against inflationary depreciation and volatility.

Methodology

The wavelet-based measures of Rua (2010) and Olayeni (2016) are adopted in the current study to investigate the hedging ability of gold prices per ounce in Turkish Lira (TRY) on inflation expectations at different maturities. These measures are preferred since they can uncover relation dynamics within the time-frequency domain, which cannot be captured by standard econometric tools or Fourier analysis. The wavelet analysis is implemented because, as noted by Conlon, et al. (2018), the hedging effectiveness of gold may be validated at particular points in time or may vary over different frequencies, due to investors' heterogeneous expectations across short and long term horizons. In addition, the quantile regression (QR) and the quantile-on-quantile regression models are employed to investigate the direction and strength of one variable on other variables over quantiles[2].

Wavelet Cohesion of Rua (2010)

In wavelet literature, two types of wavelet functions exist, namely, the father wavelet ϕ and the mother wavelet ψ and they satisfy the following fundamental property (Crowley, 2007):

2 Upon the suggestion made by one of the anonymous reviewers, we decided to examine the relationship between the two variables by establishing this nonlinear regression model as well as linear models.

$$\int \phi(t)dt = 1 \tag{1}$$

$$\int \psi(t)dt = 0 \tag{2}$$

Here, the father wavelet (scale function or low-pass filter) is used to capture the smooth/trend (low-frequency) movements of the signal while the mother wavelet (wavelet function or high-pass filter) represents the high-frequency details or deviation from the trend by scale. In a wavelet transform, the frequency and time information from the underlying signal/data can be captured by squeezing and shifting the mother wavelets

$$\psi_{\tau,s}(t) = \frac{1}{\sqrt{s}}\psi\left(\frac{t-\tau}{s}\right) \tag{3}$$

where the frequency parameter s is a sequence of scales and controls the width of the wavelet, and the location parameter τ is a position in time that controls the location. Further, the normalization factor $1/\sqrt{s}$ is used to verify that the outcome of the wavelet transform is effectively comparable across scales and time series (Crowley, 2007).

The CWT of a given discrete time series, such as $GR(t)$, the monthly gold returns, is obtained by multiplying it by the $\psi_{\tau,s}(t)$ function

$$W_{GR(t)}(\tau, s) = GR(t) * \psi_{\tau,s}(t) = \frac{1}{\sqrt{s}}\sum_{t=1}^{N} GR(t)\,\psi^{*}\left(\frac{t-\tau}{s}\right)dt \tag{4}$$

where ψ^{*} is the complex conjugate. For capturing both the time and frequency components of $GR(t)$ simultaneously, one must change the wavelet scale, s, and translate it with the localized time index, τ. Additionally, the wavelet power spectrum can be calculated as $\left|W_{GR(t)}(\tau, s)\right|^2$, which measures the relative contribution at each time and scale to the time series' total variance (Torrence and Compo, 1998).

Similarly, the cross-wavelet spectrum between $GR(t)$ and the monthly expected inflation rate, $EI(t)$, can be defined as $W_{GR(t),EI(t)}(\tau, s) = W_{GR(t)}(\tau, s)W_{EI(t)}(\tau, s)$. Since the mother wavelet is complex in general, and the wavelet spectrum is complex-valued, the cross-wavelet spectrum can be divided into the real part, $\Re\left(W_{GR(t),EI(t)}(\tau, s)\right)$, and the imaginary part, $\Im(W_{GR(t),EI(t)}(\tau, s))$. By using the real part of the cross-wavelet spectrum as the numerator, the measure of wavelet correlation can be attained, as given by Rua (2010)

$$\rho_{GR,EI}(\tau,s)=\frac{\Re\left(W_{GR(t),EI(t)}(\tau,s)\right)}{\sqrt{\left|W_{GR(t)}(\tau,s)\right|^{2}\left|W_{EI(t)}(\tau,s)\right|^{2}}} \tag{5}$$

Here, the real part of the cross-wavelet spectrum measures the contemporaneous covariance between $GR(t)$ and $EI(t)$. Additionally, $\rho_{GR,EI}(\tau,s)$ denotes wavelet correlation and quantifies the co-movement between the underlying time series in the time-frequency space, such that it provides information about the strength and direction of the co-movement, both at the frequency level and over time. Similarly, the standard coefficient of correlation, $\rho_{GR,EI}(\tau,s)$, is limited between -1 and +1, and its statistical significance is estimated using the Monte Carlo simulation approach.

Olayeni CWT-Based Causality Test (2016)

Based on the wavelet cohesion of Rua (2010), Olayeni (2016) proposed a new causality test in CWT, localizing causality in time and frequency appropriately. In the test, the first step is to explain the phase difference concept between two given time series, for example $GR(t)$ and $EI(t)$, with the condition of $-\pi \leq \phi_{GR(t),EI(t)}(\tau,s) \leq \pi$.

$$\phi_{GR(t),EI(t)}(\tau,s)=tan^{-1}\left(\frac{\Im\left(W^{m}_{GR(t),EI(t)}(\tau,s)\right)}{\Re\left(W^{m}_{GR(t),EI(t)}(\tau,s)\right)}\right) \tag{6}$$

The interval $\phi_{GR(t),EI(t)}(\tau,s)\in(0,\pi/2)$ suggests that $GR(t)$ and $EI(t)$ are in-phase; that is, they move in the same direction and $GR(t)$ leads $EI(t)$. Similarly, it is inferred that $EI(t)$ leads $GR(t)$ in the case of the interval $\phi_{GR(t),EI(t)}(\tau,s)\in(-\pi/2,0)$ since they are also in-phase. Conversely, the two variables are out-of-phase, that is, they move in a reverse direction, in the case of the intervals $\phi_{GR(t),EI(t)}(\tau,s)\in(-\pi,-\pi/2)$ and $\phi_{GR(t),EI(t)}(\tau,s)\in(\pi/2,\pi)$. Furthermore, the interval $\phi_{GR(t),EI(t)}(\tau,s)\in(0,\pi/2)\cup(-\pi,-\pi/2)$ indicates that $EI(t)$ leads $GR(t)$, implying that $EI(t)$ has significant predictive information about $GR(t)$.

To separate the hidden causal links from the non-causal content, Olayeni (2016) suggests using the aforementioned phase-difference intervals to restrict the Rua (2010) correlation. By formulating an indicator function $I_{GR(t)\rightarrow EI(t)}(\tau,s)$, Olayeni (2016) describes the following equations for the case of causality from $GR(t)$ to $EI(t)$

$$I_{GR(t)\rightarrow EI(t)}(\tau,s)=\begin{cases}1, & if\ \emptyset_{GR(t),EI(t)}(\tau,s)\in(0,\pi/2)\cup(-\pi,-\pi/2)\\ 0, & otherwise\end{cases} \tag{7}$$

$$I_{GR(t)\rightarrow EI(t)}(\tau,s)=\begin{cases}1, & if\,\emptyset_{GR(t),EI(t)}(\tau,s)\in(0,\pi/2)\\ 0, & otherwise\end{cases} \tag{8}$$

$$I_{GR(t)\rightarrow EI(t)}(\tau,s)=\begin{cases}1, & if\ \emptyset_{GR(t),EI(t)}(\tau,s)\in(-\pi,-\pi/2)\\ 0, & otherwise\end{cases} \tag{9}$$

where Eq. (7) refers to a comprehensive causal link from $GR(t)$ to $EI(t)$; Eq. (8) purports a negative or out-of-phase causality from $GR(t)$ to $EI(t)$; and Eq. (9) shows a positive or in-phase causality from $GR(t)$ to $EI(t)$.

Inputting the lead-lag information through the indicator function into the Rua (2010) wavelet correlation formula, the proposed Granger causality can be described for the causal link from $GR(t)$ to $EI(t)$ as shown in Eq. (10) and from $EI(t)$ to $GR(t)$ as shown in Eq. (11).

$$G_{GR(t)\rightarrow EI(t)}(\tau,s)=\frac{\mathfrak{I}\left\{s^{-1}|\mathfrak{R}\left(W^{m}_{GR(t)\rightarrow EI(t)}(\tau,s)\right)I_{GR(t)\rightarrow EI(t)}(\tau,s)|\right\}}{\mathfrak{I}\left\{s^{-1}\sqrt{|W^{m}_{GR(t)}(\tau,s)|^{2}}\right\}\cdot\mathfrak{I}\left\{b^{-1}\sqrt{|W^{m}_{EI(t)}(\tau,s)|^{2}}\right\}} \tag{10}$$

$$G_{EI(t)\rightarrow GR(t)}(\tau,s)=\frac{\mathfrak{I}\left\{s^{-1}|\mathfrak{R}\left(W^{m}_{EI(t)\rightarrow GR(t)}(\tau,s)\right)I_{EI(t)\rightarrow GR(t)}(\tau,s)|\right\}}{\mathfrak{I}\left\{s^{-1}\sqrt{|W^{m}_{EI(t)}(\tau,s)|^{2}}\right\}\cdot\mathfrak{I}\left\{b^{-1}\sqrt{|W^{m}_{GR(t)}(\tau,s)|^{2}}\right\}} \tag{11}$$

$G_{GR(t)\rightarrow EI(t)}(\tau,s)$ is a measure of in-phase (positive) causality if the indicator function $I_{GR(t)\rightarrow EI(t)}(\tau,s)$ holds over $\emptyset_{GR(t),EI(t)}\in(0,\pi/2)\cup(-\pi/2,0)$. Similarly, $G_{GR(t)\rightarrow EI(t)}(\tau,s)$ is a measure of out-of-phase (negative) causality if the indicator function $I_{GR(t)\rightarrow EI(t)}(\tau,s)$ holds over $\emptyset_{GR(t),EI(t)}\in(-\pi,-\pi/2)\cup(\pi/2,\pi)$, indicating a adversely predictive information flow from $GR(t)$ to $EI(t)$ over those frequency intervals.

Quantile-on-quantile method

To investigate the effects of the quantiles of gold returns on the quantiles of the inflation expectations and vice versa, we adopted the quantile-on-quantile regression approached proposed by Sim and Zhou (2015), which starts with the postulating the following equation

$$EX_t=\beta^{\theta}(GL_t)+\varepsilon_t^{\theta} \tag{12}$$

where EX_t and GL_t imply the inflation expectations (as dependent variable) and gold returns in month *t* at monthly or annual frequencies and ε_t^{θ} denotes an error term with a zero θ -quantile. Since the relationship function, $\beta^{\theta}(\cdot)$, is assumed to be priori unknown, it can be linearized by taking a first-order Taylor expansion around GL^{τ}, the τ-quantile of the gold returns (GL_t), and a new equation emerges

$$\beta^{\theta}(GL_t) \approx \beta^{\theta}(GL^{\tau}) + \beta^{\theta'}(GL^{\tau})(GL_t - GL^{\tau}) \tag{13}$$

Or it can be rewritten as

$$\beta^{\theta}(GL_t) \approx \beta_0(\theta,\tau) + \beta_1(\theta,\tau)(GL_t - GL^{\tau}) \tag{14}$$

Finally, one can obtain the following

$$EX_t = \underbrace{\beta_0(\theta,\tau) + \beta_1(\theta,\tau)(GL_t - GL^{\tau})}_{*} + \varepsilon_t^{\theta} \tag{15}$$

if Equation (14) is substituted into Equation (12). To capture the overall dependence between EX_t and GL_t, we replace GL_t and GL^{τ} with their estimated counterparts $\widehat{GL}_t$ and $\widehat{GL}^{\tau}$, respectively.

By solving the following minimization problem, we can get the estimates $\hat{\beta}_0(\theta,\tau)$ and $\hat{\beta}_1(\theta,\tau)$

$$\min_{b_0,b_1} \sum_{i=1}^{N} \rho_{\theta} \left[EX_t - b_0 - b_1\left(\widehat{GL}_t - \widehat{GL}^{\tau}\right)\right] \times K\left(\frac{F_n\left(\widehat{GL}_t\right) - \tau}{h}\right) \tag{16}$$

where ρ_{θ} is the tilted absolute value function and yields the conditional quantile of the inflation expectations, EX_t, as the solution and h is the optimal bandwidth parameter of the Gaussian kernel function, $K(\cdot)$, which is employed to weight the observations in the neighborhood of $\widehat{GL}^{\tau}$. Furthermore, these weights are inversely associated with the distanced observations, $\widehat{GL}^{\tau}$ and $\widehat{GL}_t$, in the empirical distribution function of $\widehat{GL}_t$, given by

$$F_n\left(\widehat{GL}_t\right) = \frac{1}{n}\sum_{k=1}^{n} I\left(\widehat{GL}_t > \widehat{GL}_k\right) \tag{17}$$

from the distribution function value of τ, corresponding with GL^{τ}.

Note that, we decide using the Silverman optimal bandwidth parameter[3] which is given by

$$h = \frac{a\sigma}{\sqrt[3]{N}} \tag{18}$$

where σ is equal to $\min(IQR)\,/1.34, std(GL))$, IQR and N indicate the inter-quantile range and the sample size, respectively, and a is numerically determined as 3.49.

Data

The dataset consists of monthly observations of inflation expectations and gold returns per ounce in TRY provided by the electronic data delivery system of the Turkish Central

3 We are grateful to Dr. Olayeni for providing the Eviews add-ins publicly available at https://olayeniolaolu.blogspot.com/2021/11/quantile-on-quantile-regression-qqr.html [January, 2, 2022].

Bank Database and Gold Council, respectively. It covers a 15-year period, from April 2006 to December 2020, with a sample size of 177 monthly and annual return observations. Table 1 reports the summary of the statistics for the returns series.

Table 1
Descriptive Statistics of Time Series

Variables	Mean	Maximum	Minimum	Std. Dev.	Skewness	Kurtosis	JB	N
EXP_INF_M	0.6809	2.0500	-0.1100	0.3519	0.7537	4.2785	28.81***	177
EXP_INF_Y	8.0975	17.3800	5.4400	2.3683	2.1644	7.4455	283.95***	177
GOLD_M	1.6303	28.4097	-13.4727	6.1120	0.4497	4.5459	23.59***	177
GOLD_Y	20.1001	60.3057	-22.8809	16.9544	-0.1534	2.8825	0.8000	177

Note: *** shows rejection of the null hypothesis of normality at a 99 % level of confidence. JB denotes the result of the normality test of Jarque-Berra and *N* is the observation number.

It is observed that all variables exhibit a positive average mean during the test period, and gold returns have higher average values as compared to the average values of inflation expectations, regardless of data frequency. The maximum values of monthly and annual inflation expectations (2.05% & 17.38%) and monthly gold returns (28.41%) were observed during the currency crisis in Turkey in the second half of 2018, largely driven by domestic events as well as conflicts with the USA due to Trump administration policies. However, the largest yearly gold return (60.30%), which was witnessed during the COVID-19 pandemic, was fueled by the negative effects of the global pandemic and the weakening Turkish currency with a 41.5% depreciation against the US Dollar (USD). This situation led Turks to seek safety in gold as well as raise their foreign currency deposits from $194.62 billion to $221.04 billion. The minimum values of inflation expectations (-0.11%) and gold returns (-13.47%) for monthly observations were recorded in May 2013 and December 2020. The minimum value of inflation expectations (5.44%) for annual observations was recorded in April 2006, just before the depreciation of TRY from 1.325 to 1.425 against the USD. Furthermore, the minimum value of gold returns (-22.88%) for annual observations was recorded in June 2013, when it was announced that the US Federal Reserve planned to taper its latest bond-buying program, QE3. It can also be observed, using standard deviation measures with decreasing frequencies, that gold prices were more volatile than inflation expectations. Inflation expectations and monthly gold returns are positively skewed whereas annual gold returns are negatively skewed. However, the variables differ in terms of their kurtosis, with the annual gold returns exhibiting lower excess kurtosis than the other variables, implying that all are leptokurtic. Supporting the measurement of skewness and kurtosis, the JB test statistic strongly rejects the assumption of normality for three out of the four variables at a 1% level of significance.

Results and Discussion

Table 2 reports the findings of the Lee and Strazicich (2003) unit root test with multiple structural breaks. Following the procedure described in the paper, we computed the relevant test statistics for Model A and Model C through publicly available Gauss codes, allowing for up to two unknown structural breaks. The results suggest that three out of the four variables are found to be stationary in level for Model A (Exp_Inf_M, Exp_Inf_Y, and Gold_M) and Model C (Exp_Inf_M, Gold_M, and Gold_Y). Considering these results together, we can assume that all variables are stationary; that is, they are *I*(0).

Table 2

Lee and Strazicich's (2003) Unit Root Test Results

Model A	**LM**	**10%**	**5%**	**1%**	**ʎ1**	**ʎ2**	**BP1**	**BP2**
EXP_INF_M	-3.753*	-3.504	-3.842	-4.545	0.24	0.48	2009-10	2013-04
EXP_INF_Y	-3.929**	-3.504	-3.842	-4.545	0.79	0.86	2017-11	2018-12
GOLD_M	-12.988***	-3.504	-3.842	-4.545	0.53	0.55	2014-01	2014-05
GOLD_Y	-3.058	-3.504	-3.842	-4.545	0.38	0.84	2011-11	2018-07
Model C	**LM**	**10%**	**5%**	**1%**	**ʎ1**	**ʎ2**	**BP1**	**BP2**
EXP_INF_M	-7.79***	-5.320	-5.730	-6.320	0.82	0.84	2018-05	2018-08
EXP_INF_Y	-5.165	-5.320	-5.730	-6.320	0.72	0.86	2016-10	2018-12
GOLD_M	-14.907***	-5.270	-5.590	-6.160	0.19	0.37	2009-01	2011-08
GOLD_Y	-7.885***	-5.270	-5.590	-6.160	0.37	0.43	2011-08	2012-07

Note: The rejection of null hypothesis of nonstationarity, at 1%, 5%, and 10% significance levels, is denoted by *, **, and *** respectively. "Model A" and "Model C" can be defined, respectively, as a model with a break in intercept and a model with a break in intercept & trend. ʎ1 (ʎ2) denotes the location of the first (second) break and is used to determine the critical value. Similarly, the abbreviation BP1 (BP2) stands for the time location of the first (second) structural breakpoint.

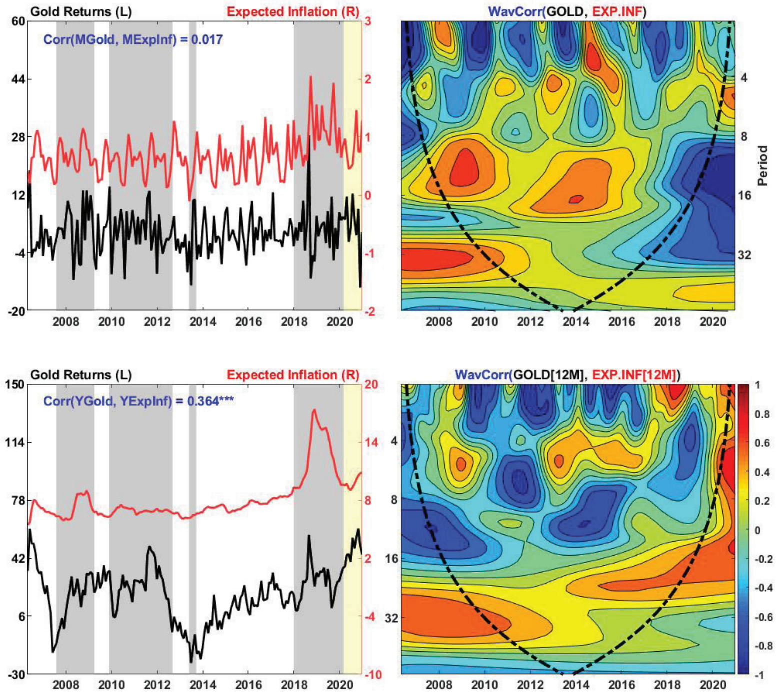

Figure 2. Time Path of Expected Inflation and Gold Returns from Rua Correlation Estimations (2010) between Time Series

Figure 2 depicts Rua's (2010) measure of cohesion between the monthly and annual growth rates during the tested period in the second column. Before proceeding further, it should be noted that the correlation relationship between our variables is positive, regardless of maturity. However, the direction of the relationship is positive, albeit not significantly, for monthly observations, whereas the annual returns are significantly positively correlated during the sample period, as expected and common in the existing literature. On the other hand, the results of wavelet-based correlation estimations show that the dynamics of the interdependence between variables are scale-independent, implying they are time varying and heterogeneous over time and across frequencies. It is observed that the monthly returns have intensive and significant negative co-movements before 2008 and over the periods of 2009–2010, 2011–2012, 2013–2014, and 2017–2018 on the highest scale with up to a period of 4 months. Further, a huge red island located on the 8–32 months band of scale at the right-hand side of the plot, between 2018 and 2020, is within the negligible area; therefore, it must be neglected, as indicated by the black dashed line called the cone of influence. However, part of this island located over the 2018–2019 period is within the acceptable area and shows that the variables move in the opposite direction in the 8–16 months band of scale (i.e., in the medium term). On the other hand, a visual inspection suggests a high degree of coherence between the variables during the period of 2008–2010 and in 2014 at the intermediate frequencies, corresponding to the 8–16 months band of scale, coinciding with the 2007–2009 GFC and the tapering of the QE3 launched by the Federal Reserve.

A similar but intensified pattern is observed at intermediate frequencies for the annual returns over the tested period. In particular, significantly negative cohesions identifiable as blue islands are observed at higher frequencies corresponding to the less than 4 months band of scale over the periods 2009–2010, 2012–2014, and 2015–2017; at 8–16 months band of scale before 2010; at 4–8 months band of scale over 2011–2013; at 6–14 months band of scale over 2013–2016; and 2–6 months band of scale over 2018–2019. Furthermore, a moderate level of wavelet cohesions ranging between 0.60 and 0.40 is clustered at the 6–7 months band of scale over the periods 2008–2009 and 2013–2014; at 20–24 months band of scale lasting from 2015 until the first half of 2018; and at lower frequencies with a 32 month scale over 2010–2011. Accounting for all of the results, the current study puts forward strong evidence for the validity of the expected inflation effect hypothesis in the long term during the crisis periods in Turkey. The results are consistent with the empirical findings of Ghazali et al. (2015), which explored a negative, but statistically insignificant association between expected inflation and gold prices in Malaysia in the short term. In agreement with our main findings, the results of Chua and Woodward (1982), Adrangi, et al. (2003), Erb and Harvey (2013), Le Long et al. (2013), and Bampinas and Panagiotidis (2015) lend further support for gold investments as an inflation hedge in the long term in the observed countries, including the USA, the UK, and Vietnam. Among these studies, Adrangi, et al. (2003) confirmed that inflation could cause a hike in the price of gold due to the hoarding demand for gold under inflationary pressures whereas the prices could be negatively affected by the industrial demand, supporting the perception that gold can provide a reliable hedging effectiveness against inflation for US investors.

Following the suggestions of Kiviaho, et al., (2014), we investigated the impact of several financial variables on the co-movement of inflation and gold prices at different time frequencies by estimating a simple OLS regression:

$$Wsr_{ij,f} = a + b_1 COVID19_i + b_2 \Delta BOND_i + b_3 \Delta CDS_i + b_4 \Delta DLRZ_i + b_5 \Delta FPI_i + b_6 \Delta FX_i + b_7 \Delta M2_i \quad (19)$$

where $Wsr_{ij,f}$ denotes the wavelet squared cohesion between the variables at the same maturity at three different frequencies (f) with the changes in stationary domestic financial variables of the 2-year government bond yields (BOND), the 5-year CDS spreads (CDS), the dollarization rates (DLRZ), the foreign portfolio investments (FPI), the average of USD–TRY exchange rates (FX), and the M2 money base, as well as the COVID-19 pandemic, as a dummy variable, in Turkey. The results are reported in the following table.

Table 3

The Effects of Financial Returns on Gold-Inflation Movements

	Short		**Medium**		**Long**	
Monthly	**T-Stat**	**Std. Error**	**T-Stat**	**Std. Error**	**T-Stat**	**Std. Error**
C	-0.079***	[0.019]	0.131***	[0.033]	0.15***	[0.006]
COVID-19	0.193***	[0.063]	-0.842***	[0.105]	-0.059***	[0.018]
ΔBOND	-0.023*	[0.013]	0.011	[0.023]	0.003	[0.004]
ΔCDS	0.008	[0.14]	0.05	[0.238]	0.057	[0.041]
ΔDLRZ	NA		-1.969	[2.847]	-0.664	[0.496]
ΔFPI	-0.208	[0.246]	0.29	[0.504]	0.042	[0.088]
ΔFX	NA		0.221	[1.174]	-0.361*	[0.204]
ΔM2	-0.327	[0.945]	-0.712	[1.82]	0.616*	[0.317]
R2	0.0678		0.2989		0.1068	
F-Statistic	2.472**		10.234***		2.871***	
	Short		**Medium**		**Long**	
Yearly	**T-Stat**	**Std. Error**	**T-Stat**	**Std. Error**	**T-Stat**	**Std. Error**
C	-0.116***	[0.022]	0.05***	[0.016]	0.109***	[0.007]
COVID-19	0.699***	[0.071]	0.437***	[0.052]	-0.199***	[0.03]
ΔBOND	-0.009	[0.015]	-0.003	[0.011]	0.001	[0.007]
ΔCDS	-0.183	[0.16]	-0.148	[0.11]	0.01	[0.054]
ΔDLRZ	-0.59	[1.913]	0.218	[1.416]	-1.321*	[0.784]
ΔFPI	-0.779**	[0.338]	NA		NA	
ΔFX	-0.635	[0.789]	0.912*	[0.482]	NA	
ΔM2	0.753	[1.223]	-0.786	[0.906]	NA	
R2	0.404		0.315		0.219	
F-Statistic	16.29***		12.933***		11.994***	

Note: ***, **, and * indicate rejection of the null hypothesis at a 99%, 95%, and 90% level of confidence, respectively. Any variable that affects the significance of the others was excluded from the model (denoted with NA). The short, medium, and long term co-movements represent the average of high-frequency scales (less than 8 months), medium-frequency scales (corresponding to 8–32 months), and low-frequency scales (over 32 months), respectively (Kiviaho, et al., 2014).

The findings mentioned in Table 3 reveal that the effect of the ongoing COVID-19 pandemic on the co-movement of inflation and gold is significant at the 1% level of significance for two maturities, but the intensity decreases and the direction switches from positive to negative as the time scale increases. Notably, all financial variables, except the changes in CDS spreads, are significant in at least one case. The findings show that the change in USD–TRY, for example, is the most influential factor among the financial variables, being negatively significant on the monthly returns in the medium term and positively significant on the annual returns in the long term, at the 10% significance level. The changes in bond yields and FPI are statistically and negatively significant at the 10% and 5% significance levels for the monthly and annual return series in the short term, respectively. As expected, the coefficient for the money supply, M2, and the dollarization rate are positively and negatively significant at the 10% level on the monthly and annual returns in the long term, respectively. This implies that changes in these variables have different impacts on the co-movement of inflation expectations and gold returns. These results are partially in line with the findings of Batten, Ciner, & Lucey (2014), that discovered a significant negative correlation between the USD index and the time variation in gold's CPI beta, further confirming the role of gold as a monetary asset. Furthermore, Batten, et al. (2014) also found that past information on the USD index and T-bill and T-bond interest rate variations were useful in predicting gold's CPI beta with seven, six, and ten lags. Finally, the results of impulse response functions revealed a negative association between gold's CPI sensitivity and interest rate movements, implying that falling interest rates documented the increasing importance of inflation on gold prices. They argued that these observations were supporting the view that monetary easing fuels fears of higher inflation, which further produces positive co-movement with gold prices.

The CWT-based causality method proposed by Olayeni (2016) was utilized to discover the direction of causality, if any, between the series. The results of the same are given in Figures 3 and 4. It should be noted that the causal link between the aggregate, positive or in-phase, and negative or out-of-phase components are depicted in the top, middle, and bottom panels, respectively. Regarding the dependencies between monthly observations, weak bidirectional causality exists at the higher and intermediate frequencies, corresponding with less than 4 and between the 8–16 months cycle, respectively. A positive or in-phase, but unidirectional causal relationship from the expected inflation to monthly gold returns in 2009 emerges at the intermediate term, or 10–14 months cycle, by dividing the causal links into two components. A bidirectional and out-of-phase causal relationship between the variables arises in the bottom panel, evidenced by a small red island located at the higher frequencies after 2017 and by three red islands located in the short term before 2007 and over 2009-2010, and in the medium term over 2018-2019. The summary of all these findings mainly indicates that the causal relationship between the variables is largely driven by the predictive information contained in the negative inflation expectation movements on the gold returns in the short term and intermediate term during the 2007–2009 GFC and 2018–2020 currency crisis in Turkey.

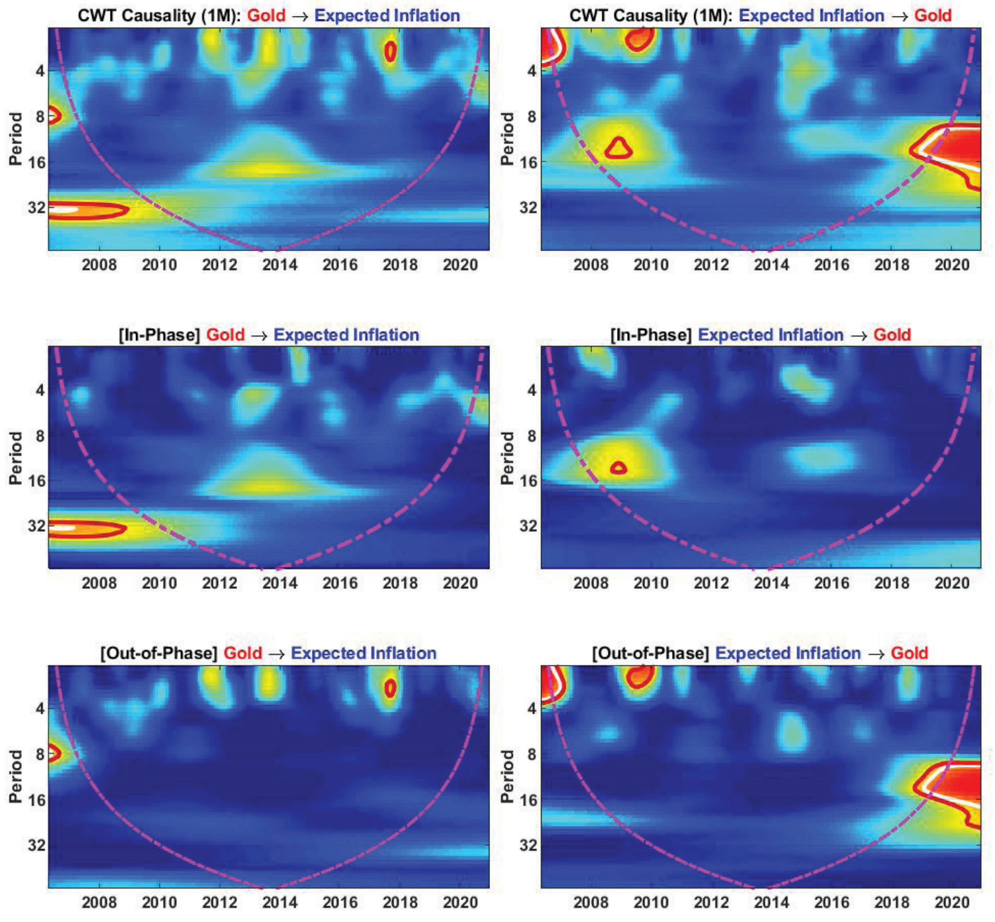

Figure 3. CWT Causality between Monthly Observations

Figure 4, on the other hand, indicates the presence of anti-phase causal impacts from the inflation expectations on the annual gold returns at higher frequencies around 2012, indicating that the annual inflation expectations from the Granger-causality test negatively impact the annual gold returns in the short term. These results largely reinforce the findings of Xu et al. (2019a), which document a negative, rather than positive, causality from the inflation expectations to the gold returns, contradicting the expected inflation effect hypothesis. The weak, but significant causality from the gold returns to the inflation expectations in the current study is in line with Xu et al. (2019a), indicating that the hedging ability of gold is valid only during certain periods.

We provided the results of preliminary tests for monthly and annual observations under linear and quantile regression models in Table 4. The null of non-normality hypothesis was

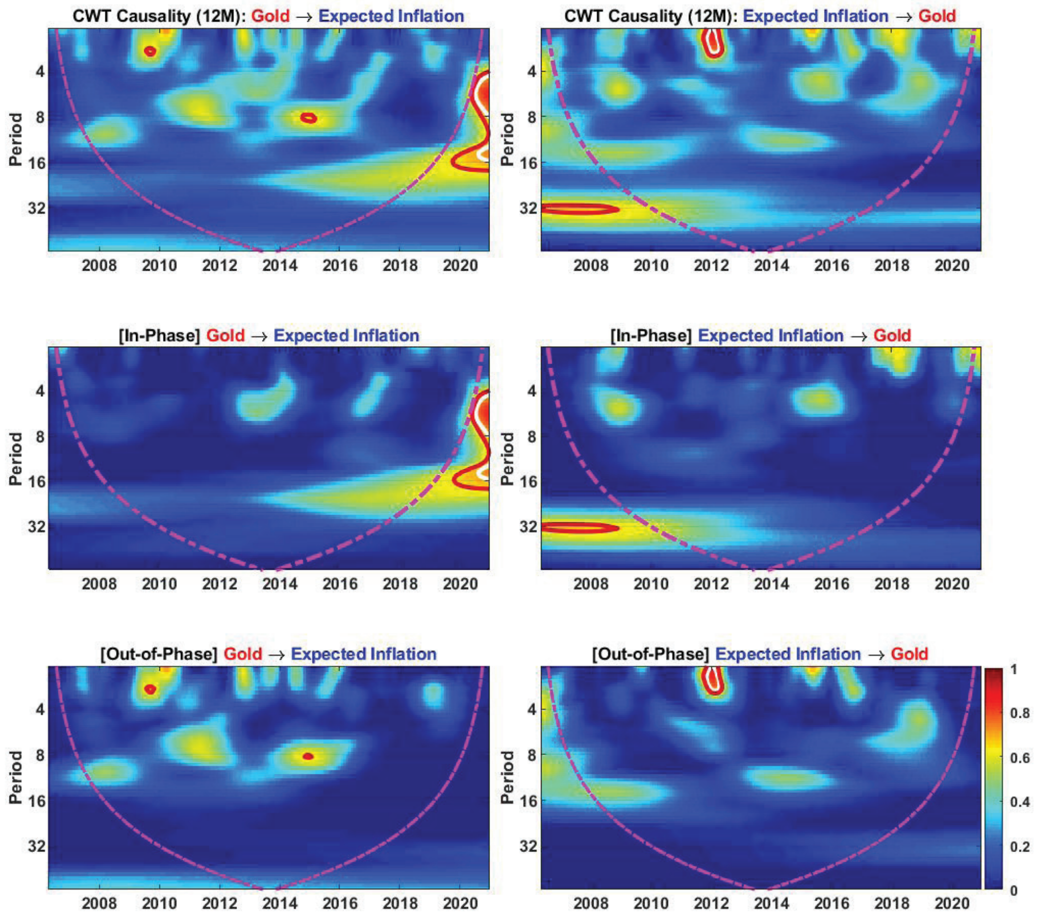

Figure 4. CWT Causality between Yearly Observations

strongly rejected for three models, except for "Gold_Y~Exp_Y". The results revealed the existence of serial correlation up to 2 lags in the three out of four models, other than the pair of "Gold_M~Exp_M". The heteroskedasticity test results implied that only the residuals of monthly series had a constant variance. All these results of residual diagnostic tests showed that the linear regression assumptions did not meet properly and, then, require us to study the relationship using nonlinear regressions. Indeed, the two stability diagnostic test—the parameter stability (Andrews, 1993) and breakpoint (Bai and Perron, 2003)—results highlighted the parameter instability and the presence of breakpoint in the three models, which justified the suitability of investigating the relationship at various quantiles.

Table 4

Preliminary Tests for Linear and Quantile Regressions

Dependent variable	**GOLD_M**	**EXP_M**	**GOLD_Y**	**EXP_Y**
Independent variable	**EXP_M**	**GOLD_M**	**EXP_Y**	**GOLD_Y**
Linear Regression				
Normality Test	22.68***	30.14***	0.3	264.55***
Serial Correlation LM Test (BG)	2.09	49***	131.87***	163.57***
Heteroskedasticity Test (BPG)	0.58	2.44	4.29**	11.03***
Max LR F-Statistic	1.698	25.054***	20.536***	160.508***
UDMax	4.055	33.372***	78.126***	113.775***
Quantile Regression				
Quasi-LR Statistic	0.829	0***	14.819***	19.361***
Slope Equality Test (Koenker and Bassett, 1982)	16.312	18.034	52.284***	58.407***
Symmetric Quantiles Test (Newey and Powell, 1987)	21.377	19.571	11.44	48.7***

Note: *** and ** indicate rejection of the null hypothesis at a 99% and 95% level of confidence, respectively.

We conducted three tests on the results (see Figure **6**) of the quantile regression, which did not require strong distributional assumptions unlike linear regressions. The results showed that (i) the explanatory power of all three estimated models, with the exception for "Gold_M~Exp_M" model, was statistically significant at the 1% level of significance [Quasi-LR Statistic]; (ii) the evidence to suggest the rejection of the null hypothesis of slope equality for the annual observations, indicating that the slope coefficients differed across quantiles and thus the conditional quantiles were not identical; (iii) significant evidence of asymmetry in one case—where the annual gold returns were being selected as an independent variable—but not in the other cases.

Figure **5** visualizes the QQ based relationship between inflation expectations and gold returns, at monthly (top panel) and annual (bottom panel) frequencies. At first glance, we observed that the impacts of inflation expectations, in terms of absolute value of QQ coefficients, on gold returns were stronger than the other way around at both frequencies. For monthly observations, the effect of inflation expectations on gold returns was relatively positive (60 per cent of all quantiles) and peaked ($\beta = 17.27$) at the upper quantiles [0.80–0.90] when inflation expectations were at a high level and hit the lowest ($\beta = -33.12$) at the upper quantiles of the two series. The impact was positive at the vast majority of quantiles of inflation expectations—with the exceptions for the quantiles ranging from 0.14 to 0.33—when gold returns were at a low [0.05–0.23] and medium levels [0.57–0.76], but it turned negative at the medium and upper quantiles of gold returns as the quantile of inflation expectations increased. The effect of annual inflation expectations on gold returns was also positively strong with a higher percentage (0.756 vs. 0.65), albeit a weaker, than that of monthly observations across all quantiles. The positive effect was prominent at all quantiles of two variables from 0.05 to 0.48 and reached its peak of almost 14.65 at the quantile of (0.05) inflation expectations.

The same impact was shown to hold at the first two lower quantiles of inflation expectations through all the quantiles of gold returns. As the level of inflation expectation increased, the positive impact relatively diminished from the lower to medium quantile of gold returns, but started to strengthen at the remaining quantiles. Similarly, inflation expectations exhibited a positive impact at higher quantiles of gold returns when they were in the extreme lower ranges, however, the coefficients switched sign from positive to negative starting from the third [0.14] to the last quantile. The number of quantiles in which the negative effect was valid increased at the lower to medium quantiles [0.14–0.67], and it remained unchanged until the last quantile as the level of inflation expectation increased.

We presented the results of QQ regressions in the second column of Figure **5** where gold returns at both frequencies were chosen as an explanatory variable. When compared with the results aforementioned above, the effect of monthly gold returns on inflation expectations in terms of coefficients was considerably weaker at all quantiles. As the level of gold returns increased, the effect was slightly positive for the lower quantiles and strongly positive for the top quantile of inflation expectations. The results also showed a growing path of the negative coefficients for the normal and upper quantiles of inflation expectations and from the lower to the upper quantiles of gold returns. Turning our attention to the annual observations, we see that gold returns documented a kite-shaped pattern and positive impact on the inflation expectations across all quantiles, i.e., the effect was strengthening with the increasing of the quantile of two growth rates. However, this effect was negative for the lower quantiles of two variables; upper quantiles of inflation expectations when gold returns were at a low level; and at the upper four quantile of inflation expectations and the last quantile of gold returns.

We plotted the estimation results of two quantile approaches in Figure ***6***. The results suggested that both estimates were approximately the same in terms of direction of relationship, but slightly different in terms of strength for monthly observations. In the upper panel, we found that the average QQ estimates of the slope coefficients (QQR) and the quantile regression estimates (QR) for monthly observations varied moderately across all quantiles, whereas there were almost similar paths for the annual observations (see the bottom panel), that is, they converged nearly at all quantiles, exception for the last upper quantiles.Further, the findings revealed that the QR coefficients for annual observations were positively significant (depicted by a yellow circle) at all quantiles, except for the upper quantiles of expected inflations, whereas none of the p-values of the QR coefficients were less than a 10% significance level for the monthly observations. Accordingly, the results virtually validate the QQR regression estimations in Figure **5** and showed that the effect of monthly observations on each other was weak and heterogonous, i.e., the impact was negative or positive varied according to the distribution of returns. However, it was significantly positive through all quantiles for annual observations, and strengthened (declined up to the quantile 0.71, after which started to rise) as the quantile of gold returns (inflation expectations) increased. These results are closely in

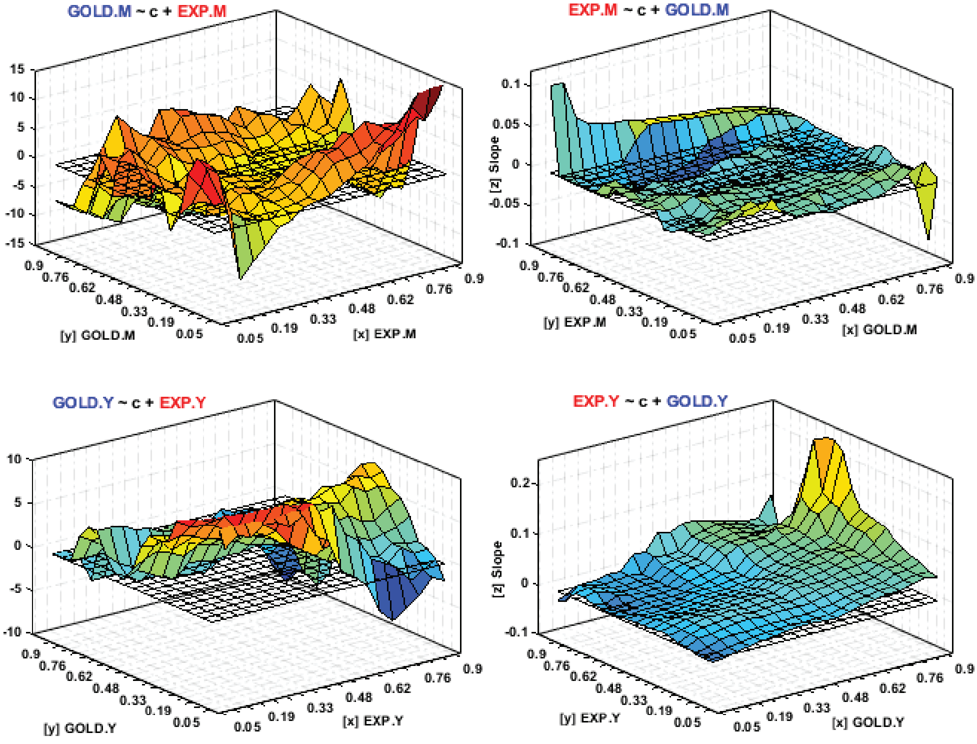

Figure 5. Quantile-on-quantile regression relationship between monthly and annual observations

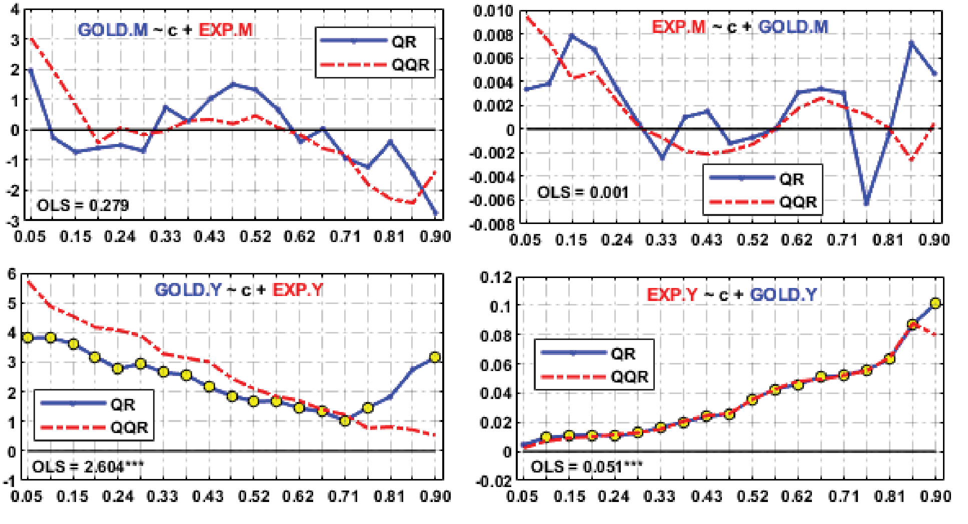

Figure 6. The comparison of QR and QQR estimates of the slope coefficients for monthly (top) and annual (bottom) observations

line with Wang, et al. (2011) and Shahzad, et al. (2019), who documented an asymmetrical inflation-gold linkage that depended on the size and sign of the inflation shocks. In accordance with our findings, Sui, et al. (2021) found that the hedging effectiveness of gold against inflation was strongly related to market condition (distribution of growth rates) and the nature of macroeconomic shocks in Turkey.

Conclusions

We investigated the relationship between inflation expectations and gold returns of monthly and annual maturities through the application of wavelet cohesion and causality tests as well as linear and nonlinear regression models, using data from Turkey over the period of 2006–2020 with a total of 177 observations. We further examined the relationship in terms of wavelet correlation at different time scales and identified the main factors among the selected macroeconomic and financial variables including interest rates, CDS spreads, dollarization rates, FPI, USD–TRY exchange rates, and the M2 money base in explaining the co-movements between gold prices per ounce in TRY and inflation expectations. The findings of Rua's (2010) wavelet cohesion revealed significantly negative cohesion in the short term and significantly positive cohesion in the long term, indicating that the hedging ability of gold prices exists only in the long term during the crisis periods. This further confirms the validity of the expected inflation effect hypothesis in Turkey. The results reinforced the conclusions drawn by Chua and Woodward (1982) and Adrangi, et al. (2003) in the USA and Le Long et al. (2013) in Vietnam. The OLS results, conversely, showed that the ongoing COVID-19 pandemic was the most prominent factor on the movement of inflation and gold at all scales for the two maturities whereas the changes in CDS spread were an insignificant factor for the same. By supporting the findings of Batten et al. (2014), the current study also discovered that the changes in interest rate and portfolio investments and the movements in foreign exchange rates and dollarization rates seem to have a significantly negative impact on the relationship between gold and inflation expectations in the short term and long term, respectively. The rise in the M2 money base produced a significantly positive impact on the gold-inflation co-movement in the long term, as expected, for Turkish investors seeking alternatives besides interest-bearing assets—which had prices implicitly controlled by policymakers—to buying gold, real estate (Gulseven and Ekici, 2020), and cars. The CWT-based Granger-causality test provided limited evidence for out-of-phase and unidirectional causal linkage, from inflation expectations to gold returns, in the higher and medium frequency intervals. This was corroborated by Xu et al. (2019a), which found that inflation expectations caused negative gold returns in the USA. These findings further suggested that a decrease in inflation expectations significantly leads to a decrease in gold prices in the short and intermediate terms in Turkey. The QQR results showed that the effects of inflation expectations on gold price changes were positive and stronger than the other way around at both frequencies and changed considerably according to the return distributions. These results suggest that the hedging ability of inflation mostly hold, but varied under different economic conditions and data frequencies.

The implications of the results are significant for the monetary policies under an inflation-targeting regime that is aimed at managing inflation expectations and controlling inflation pressures in Turkey. Policymakers may monitor movements in bond and currency markets as well as dollarization rate and foreign portfolio investments to predict the direction of the gold-inflation co-movement, and thereby, comprehend investors' perceptions of inflation expectations for achieving sustainable financial stability and economic growth. Moreover, the findings regarding the gold and inflation expectation co-movements and causality relationship are important for portfolio and risk management during the normal market conditions as well as hedging and speculative activities during the crisis periods in the short and long term periods. This study accounts for the effects of the domestic financial variables on the gold-inflation relationship, but leaves the effects of global factors for future research in the field.

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