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From safe-haven to industrial driver: The influence of gold and precious metals on manufacturing growth in Türkiye

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A B S T R A C T

This study empirically analyzes the transformation of gold and precious metals from traditional safe-haven assets to industrial drivers in Türkiye, focusing on their effects on manufacturing growth for the period 2003M1–2025M2. Employing the Fourier-ARDL cointegration test, Fourier-Toda Yamamoto causality analysis, and Wavelet Coherence Analysis (WTC), we find a positive and significant long-term relationship between precious metal prices and manufacturing production (MPI). Inflation and crisis periods are shown to have negative effects on output. While causality tests reveal a unidirectional effect of gold price shocks on manufacturing growth, WTC analysis highlights the dynamic and time-varying nature of these relationships. The findings demonstrate that precious metals, beyond their traditional role as safe-havens, exert a multifaceted influence on real sector performance in Türkiye, offering important implications for policymakers and industrial strategy.

1. Introduction

Commodities have a key role in the global economy since they are essential inputs for global production and significant outputs of many emerging economies. Hence, fluctuations in commodity prices also shape business cycles in many economies (Diebold et al., 2017). They are also strongly connected to changes in global macroeconomic conditions. The global financial crisis, the Covid-19 pandemic, and the Russian attack on Ukraine are some evidence of the interconnected nature of global challenges (Boakye et al., 2024). Another role of commodities is as financial assets, and metals are assessed within this class (Diebold et al., 2017). Precious metals attract attention due to their elevated and rising economic value. It is essential to distinguish four precious metals—gold, silver, platinum, and palladium—from other industrial metals, such as aluminum, nickel, tin, zinc, lead, and copper, as these two groups exhibit different hedging characteristics and varying exposures to macroeconomic factors (Rana & O'Connor, 2023; Kazak, Rahman, et al., 2025). Furthermore, gold has had a significantly different value throughout human history. Throughout history, gold has been used originally as jewelry, and subsequently as a method of storing wealth and facilitating exchange. Until the 20th century, the use of gold as jewelry and a tool for transactions remained the top function (Baffes et al., 2022). Following World War II, gold became a reserve asset at the Bretton Woods Conference in 1944. After the system's collapse in the early 1970s, gold emerged as a significant component of international reserve assets for countries (Bildirici et al., 2016). In 1971, the United States could no longer maintain the convertibility of the dollar to gold and had to suspend it due to excessive dollar issuance. Since then, a global gold market has developed, operating around the clock and accommodating a variety of derivative instruments. As can be seen in Fig. 1, gold prices have become increasingly volatile since that time (Trück & Liang, 2012). Subsequently, gold has been utilized as an investment tool during periods of economic and geopolitical turbulence (Baffes et al., 2022). As shown in Fig. 1, gold prices tend to rise in response to escalating stress in the geopolitical landscape and global economy, as evidenced by events such as the 9/11 attacks, the global

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financial crisis, the COVID-19 pandemic, and the Russian invasion of Ukraine.

The price of gold is influenced by the dynamics of supply and demand, but the formation of gold prices is not solely determined by economic factors, such as geopolitical events or market speculation. Additionally, geopolitical and social developments significantly impact gold prices (Yurdakul & Sefa, 2015). Unlike other financial assets, gold prices tend to rise in response to negative market shocks (Baur & McDermott, 2010).

Looking at the gold market more closely, there is both government and private demand for gold. Central banks aim to hold significant amounts of gold as a strategic asset. Private demand is classified into two categories: investment demand and non-investment demand. Investment demand includes bullion and bars, while non-investment demand encompasses usage in the jewelry and dental sectors, as well as other manufacturing areas (Fei & Adibe, 2010). Baur and McDermott (2010) state that demand for gold in jewelry, dentistry, and industrial applications tends to follow the business cycle, as it is influenced by consumers' spending power. However, the demand for gold among investors appears to be counter-cyclical, as it tends to increase during times of recession (Baur & McDermott, 2010). Another approach to understanding short-run demand for gold categorizes it into two types: 'use demand' and 'asset demand.' The demand for gold pertains to its applications in jewelry, medals, and electrical equipment, and is inversely proportional to gold prices; an increase in gold prices results in a decrease in demand. In contrast, asset demand is influenced by expectations regarding the dollar exchange rate, inflation, market sentiment, the returns of other assets, and the lack of correlation with other assets (Levin & Wright, 2006). Among the four precious metals, gold is primarily used in the jewelry and electronics sectors, while silver is utilized electronics, films, photographic emulsions, industrial applications, and jewelry. Additionally, platinum group metals, specifically platinum and palladium, are employed in refining crude oil, in carbon-based catalysts, and in electronic devices (Canda et al., 2015). Therefore, among these precious metals, gold holds a unique significance due to its demand as a substantial long-term investment and store of value.

On the supply side, the determinants of gold quantity include mining activities, sales of gold reserves, and the recycling of gold scrap. Following the Gold Rushes in the second half of the 19th century, gold production increased during the 20th century. However, challenges remain in discovering new gold resources and in the extraction process (Fei & Adibe, 2010). In the short term, the price of gold is influenced by supply and demand dynamics (Levin & Wright, 2006; Trück & Liang, 2012). Furthermore, Trück and Liang (2012) highlight additional factors affecting gold prices, such as hoarding and disposal; interest rates; returns on bonds, equities, and real estate; declines in the financial sector; and speculation in the gold market.

When considering all these factors—namely, relatively inelastic supply and counter-cyclical demand—gold can serve as a safe haven during times of financial turmoil and global uncertainty (Baur & McDermott, 2010; Bildirici & Ozaksoy Sonustun, 2018). This dynamic tends to drive gold prices higher during crisis periods. One hypothesis that explains the demand for gold is the safe haven hypothesis, which asserts that this asset is uncorrelated or negatively correlated with other assets or portfolios, during periods of market stress (Baur & Lucey, 2009).

Fluctuations in commodity prices are crucial to understanding the potential effects of raw materials on the economy, as significant price increases also lead to rising costs (Rossen, 2015). Therefore, examining the movements in gold prices is essential to reveal their impact on the activities of the manufacturing industry. If commodities serve as substitutes for one another in the consumption and production of other goods, such as platinum and palladium, then price divergence remains somewhat limited (Rossen, 2015). Gold notably distinct compared to other precious metals, namely silver, platinum, and palladium, due to its relatively minimal industrial usage (Bildirici & Ozaksoy Sonustun, 2018). As of Q1 2025, gold demand by sector is as follows (MacroMicro, 2025): 36 % in jewelry manufacturing, 6.67 % in electronics and dentistry, 45.76 % in investment, and 20.2 % by central banks and other institutions. Considering the applications of gold in electronics and dentistry, its share in global gold demand appears disproportionately low. Nearly half of the global gold demand arises from investment, while 36 % is generated by jewelry. This indicates that the industrial use of gold worldwide is relatively limited. Sari et al. (2010) note that although both gold and silver are utilized in the jewelry industry and traded as investment assets, silver is more commodity-driven than gold due to its diminishing role as a monetary element. Silver demand statistics support this assertion. As of 2023, the share of industrial demand for silver is 54.7 %, while jewelry demand and net hedging demand account for 16.9 % and 1.02 %, respectively (Silver Institute, 2025). These statistics illustrate the significant demand for silver in industrial production. In the case of platinum, its predominantly industrial use is evident. By 2024, 37.4 % and 19.95 % of total demand will stem from automotive and industrial applications, while jewelry and investment demand account for 24.2 % and 8.46 %, respectively (World Platinum Investment Council, 2025). Finally, palladium exhibits a similar trend, with nearly 83 % of its demand coming from the automotive sector; 16.2 % from industrial use; and 0.9 % from the jewelry sector as of 2022 (Statista, 2025). These statistics further highlight the distinct characteristics of

Fig. 1. Gold prices source: Goldprice (2025).

gold in terms of demand.

Gold prices are influenced by various factors, including demand for consumption, inflation expectations, investment trends, gold reserves, government borrowing, speculation, gold supply, lack of safe havens, interest rates, and declines in financial markets (Bildirici & Ozaksoy Sonustun, 2018; Trück & Liang, 2012). An increase in gold demand, driven by economic growth and improved economic welfare, may lead to a rise in gold prices (Bildirici & Ozaksoy Sonustun, 2018). This increase in gold prices can impact consumer purchasing power, potentially affecting the manufacturing industry. In this context, the expected effect of rising gold prices on manufacturing activities is positive. On the other hand, gold is utilized in industrial production, even though it has a low share compared to other precious metals. Therefore, an increase in gold prices results in escalating costs (Rossen, 2015), which can negatively impact manufacturing activities, particularly during economic downturns. In this context, the expected effect of gold prices on the manufacturing industry is negative. Additionally, gold prices tend to rise in response to high inflation expectations, a lack of alternative safe havens, and insufficient positive returns from other assets. During times of uncertainty and economic turbulence, individuals seek trusted investment instruments (Bildirici & Ozaksoy Sonustun, 2018). Beyond its safe-haven property, gold also serves as a hedging and diversification tool (Gençyürek & Ekinci, 2023). Consequently, an increase in gold prices may lead to a decline in manufacturing industry activities due to the economic downturn. In summary, a positive effect of gold prices on manufacturing activities indicates economic recovery and prosperity, while a negative effect signifies economic turmoil.

The existing literature reveals a gap concerning the impact of gold prices on production within the manufacturing industry. To address this gap, we investigate the effect of global gold prices on the manufacturing sector in Türkiye. Additionally, we analyze the influence of the precious metals sub-index, the composite precious metals index, the USD/TRY exchange rate, the consumer price index, the BIST-100 index, and Brent oil prices. The precious metals sub-index, which comprises futures contracts on gold and silver (Bloomberg, 2025), reflects the demand for these scarce resources (Van & Bao, 2022). Consequently, it can be inferred that this index declines when economic stability increases, while it rises when confidence in the economic environment diminishes. The composite precious metals index, which includes gold, silver, platinum, and palladium, represents the aggregated price of these precious metals. We anticipate a similar relationship here. In other words, an increase in the index may indicate that investors are seeking safe instruments in a volatile economic environment, whereas a decrease may suggest a shift towards riskier assets in a more stable economic context. By utilizing these two indices, we analyze the local transmission channels through which precious metal prices affect the manufacturing industry in Türkiye. When it comes to the exchange rate, an increase in USD/TRY, referring to depreciation of the national currency of Türkiye, makes production activities in the manufacturing industry more expensive, leading to a decrease in these activities. An increase in the consumer price index, which is an indicator of the purchasing power, may lead to a reduction in manufacturing industry activity. The BIST-100, an indicator of stock prices of the top 100 firms registered in the Borsa Istanbul, is affected by changes in the global economic and political environment, firm profits, and other factors. An increase in the BIST-100 refers to an increase in the value of stocks; it leads to a rise in manufacturing activities. Conversely, a decrease in the BIST-100 corresponds to a decrease in these areas. Finally, Brent oil prices also affect the manufacturing industry via the changing costs of production, meaning that an increase in oil prices leads to an increase in production costs, hence a decrease in the manufacturing industry.

The present study offers empirical, methodological, and political contributions to the existing literature. The empirical contribution is based on the analysis of transmission channels via national and global precious metal values. The methodological contribution involves an integrated analysis that combines Fourier-ARDL cointegration to assess long-run relationships, Fourier Toda-Yamamoto for short-run dynamics, and wavelet coherence (WTC) for time-frequency analysis. The political implications of this study provide concrete policy recommendations for the Central Bank of Türkiye and financial authorities regarding the impact of gold and precious metals liquidity on real investments.

To address space constraints and to keep the main text more focused, a more detailed literature review is provided in Online Appendix A. Literature Review. This supplementary section offers readers further insights into the empirical background of the study. The data and model of the study are introduced in Section 2. Section 3 presents the methodology, and Section 4 reports the empirical results, discussing their links with the literature and hypotheses. Finally, Section 5 concludes the paper and outlines the policy implications.

2. Data and model

2.1. Data

The main objective of this study is to empirically analyze the impact of precious metal markets on manufacturing growth in Türkiye, over the period January 2003 to February 2025. In the analysis, the manufacturing production index (MPI) is used as the dependent variable, representing manufacturing production and growth (as an important component of economic growth), while the main focus is on precious metal prices and indices. In this context, the gold price (AU) and the composite precious metals index (PMI) constructed by the researchers stand out as the main independent variables. The model also includes the consumer price index (CPI), the BIST-100 index (BIST), the Brent oil price (BRENT), and a dummy variable representing economic crisis periods (Crisis) as macroeconomic and financial control variables. All series are analyzed at a monthly frequency and logarithmically transformed. The stationarity of the series is checked by unit root tests. Detailed information on the variables used is presented in Table 1.

2.2. Model and hypotheses

In this study, the ARDL Bounds Test approach is used to analyze the relationship between precious metals and macroeconomic and financial indicators in both the long and short run. In addition, the Fourier Toda-Yamamoto causality test is applied to determine the causality relationships between variables, and the Wavelet Transform Coherence analysis is applied to examine dynamic relationships in the time-frequency dimension. The model specification is constructed as shown below:

Table 1
Description of variables.

Notation	Name of Variable	Measurement Scale	Data Source
MPI (t)	Manufacturing production index (log)	Monthly Index (2021 = 100)	Turkish Statistical Institute (TurkStat-TÜİK)
AU (t)	Gold Price (TRY/ounce, log)	Month-end Prices	Bloomberg (XAU Curncy) and TCMB
PMI(t)	Precious Metals Index ($) (log)	Composite Index	Index calculated by the authors [Bloomberg (XAU, XAG, XPT, XPD)]
CPI(t)	Consumer Price Index Seasonally Adjusted (log)	Monthly Index (2003 = 100)	Turkish Statistical Institute (TurkStat-TÜİK)
BIST(t)	BIST-100 Index (log)	Month-end Index Value	Istanbul Stock Exchange (Borsa İstanbul)
BRENT (t)	Brent Oil Price (log, continuous front-month) (log)	Month-end Prices	Refinitiv (LCOc1)
Crisis(t)	Dummy (1)		

$$MPI_t = \alpha + \beta_1 AU_t + \beta_2 PMI_t + \beta_3 CPI_t + \beta_4 BIST_t + \beta_5 BRENT_t + \beta_6 Crisis_t + \varepsilon_t \tag{1}$$

in this model, manufacturing industry production index (MPI), precious metals price and indices (AU, PMI), inflation rate (CPI), stock market index (BIST), oil price (BRENT) and crisis dummy variable (Crisis). In this context, the following main hypotheses are analyzed:

✓ H1: Precious metal prices and the index (AU, PMI) have a statistically significant effect on manufacturing industry production in Türkiye.
✓ H2: There is a long run cointegration relationship between precious metals and manufacturing industry production.
✓ H3: Shocks in precious metal prices and indices causally affect manufacturing industry production.
✓ H4: The relationship between precious metals and manufacturing industry production is dynamic and cyclically variable in time and frequency dimensions.

2.3. Descriptive statistics

Within the scope of the study, the structure of the data was first examined using descriptive statistics. The relevant descriptive statistics are presented in Online Appendix Table B-1. When evaluating the table results, the mean and median values provide information about the central tendency of the distribution across all series. The closeness of the mean and median values in the AU, BIST, and MPI variables indicates that these variables exhibit a symmetric distribution. On the other hand, the high skewness and kurtosis values observed in the CPI and BRENT variables indicate the presence of extreme values and asymmetric distributions in the relevant series. The CPI variable exhibits very high kurtosis and skewness, indicating that extreme observations have an effect on the distribution. According to the results of the Jarque-Bera test, the normality assumption is rejected for numerous series, especially for CPI and BRENT variables ($p < 0.05$). This suggests that parametric test assumptions should be carefully considered in econometric analyses to be conducted on the series. Moreover, the standard deviation values allow for the comparison of the volatility level between the variables, and indicate relatively high volatility, especially in the BRENT and BIST variables.

3. Methodology

In this study, the Fourier-ADF test introduced by Enders and Lee (2012) is primarily used to analyze the stationarity of the series. Since the method has been widely adopted in the literature, the theoretical framework of the test is not presented here, and only the results are provided. In the next step, the Fourier Granger causality approach proposed by Nazlioglu et al. (2016) was used. This approach has been used in numerous studies in the literature, and therefore no further details are provided here [For details, see the following studies: Nazlioglu et al. (2016); Kazak, Abduh, et al. (2024); Kazak, Akcan, and İyibildiren (2024); Kazak, Mensi, et al. (2025)].

In the next stage, the ARDL Bounds Test method was applied to determine the long-run relationship between the variables. This method allows testing the long-run cointegration relationship in models with both I(0) and I(1) integrated series. The ARDL Bounds Test developed by Pesaran et al. (2001) is widely preferred in the literature as it provides reliable results and offers a more flexible structure compared to classical cointegration tests.

In the ARDL Bounds Test model, an ARDL model is constructed as follows:

$$\Delta Y_t = a_0 + \sum_{i=1}^{\tau} a_1^i \Delta Y_{t-i} + \sum_{j=1}^{đ} \sum_{t=0}^{q_j} \beta_{jt} \Delta X_{j,t-i} + ђ_1 Y_{t-1} + \sum_{j=1}^{đ} ђ_{2j} X_{j,t-1} + \varepsilon_t \tag{4}$$

Where "Δ" denotes the first difference, "Y_t" denotes the dependent variable and "$X_{j,t}$" denotes the independent variables. Also "τ" denotes the number of lags of the dependent variable (Y_t), "đ" denotes the total number of independent variables included in the model, and "q_{ij}" denotes the number of lag terms (lags) with which each independent variable ($X_{j,t}$) enters the model.

The existence of the long-run relationship in the ARDL Model is tested by testing whether the following equation is zero.

$$H_0 : ђ_1 = ђ_{21} = \ldots = ђ_{2đ} = 0 \tag{5}$$

in the final stage of the study, the Wavelet Transform Coherence (WTC) method is used to simultaneously analyze the multiscale interactions between variables in both amplitude and phase in the time and frequency domains. In this holistic analysis, first a continuous wavelet transform is performed with the Morlet wavelet function to reveal the dynamic structure of each time series at different frequency ranges. This approach has also been used in numerous studies in the literature, and due to page limitations, it is not necessary to provide further details here (for details, see the following studies: Kazak, Çiftçi, et al. (2024); Kazak, Saiti, et al. (2025)).

The empirical framework of the study is summarized in Fig. 2. The diagram shows the independent variables, the econometric analysis methods applied, the dependent variable, and the basic hypotheses tested. This diagram provides a comprehensive visual representation of the theoretical structure of the model, the analysis techniques used, and the basic assumptions of the study.

The results of the analyses conducted within the framework of the model are evaluated in detail in the next section.

4. Empirical results

In this section, the results of the Fourier Augmented Dickey Fuller Unit Root Test applied to examine the stationarity of all time series included in the econometric analysis are presented in Online Appendix Table B-2. Fourier Augmented Dickey Fuller Unit Root Test Results indicate that PMI, MPI and AU variables are stationary at first difference, while the other variables are stationary at level values. Therefore, the causal relationship between the variables was examined using the Fourier Toda Yamamoto causality test for variables that are stationary at different levels. The results of the Fourier Toda Yamamoto causality test are shown in Table 2.

The results of the Fourier Toda Yamamoto Causality Tests indicate that there is bidirectional causality between the dummy variable representing the economic crisis period and the MPI variable, as well as unidirectional causality from the AU variable to the MPI variable and from the MPI variable to the PMI variable.

In the next stage, the ARDL Bonding Test was conducted, and the results are shown in Table 3. When the ARDL bound test results are analyzed, it is determined that the model has a long run cointegration relationship, since the F statistic value calculated for the bound test is greater than the 1 % critical value. When the long-run coefficients of the model are analyzed, all independent variables significantly affect the dependent variable MPI. While the CPI variable and the dummy variable affect the MPI variable negatively in the long run, all other variables affect it positively. When the results of diagnostic tests are analyzed, it is found that the model does not suffer from heteroskedasticity and autocorrelation problems.

Finally, Wavelet Transform Coherence Analysis was performed, and the results are presented below. In the graphs obtained from Wavelet Transform Coherence (WTC) analysis, the vertical axis is shown as

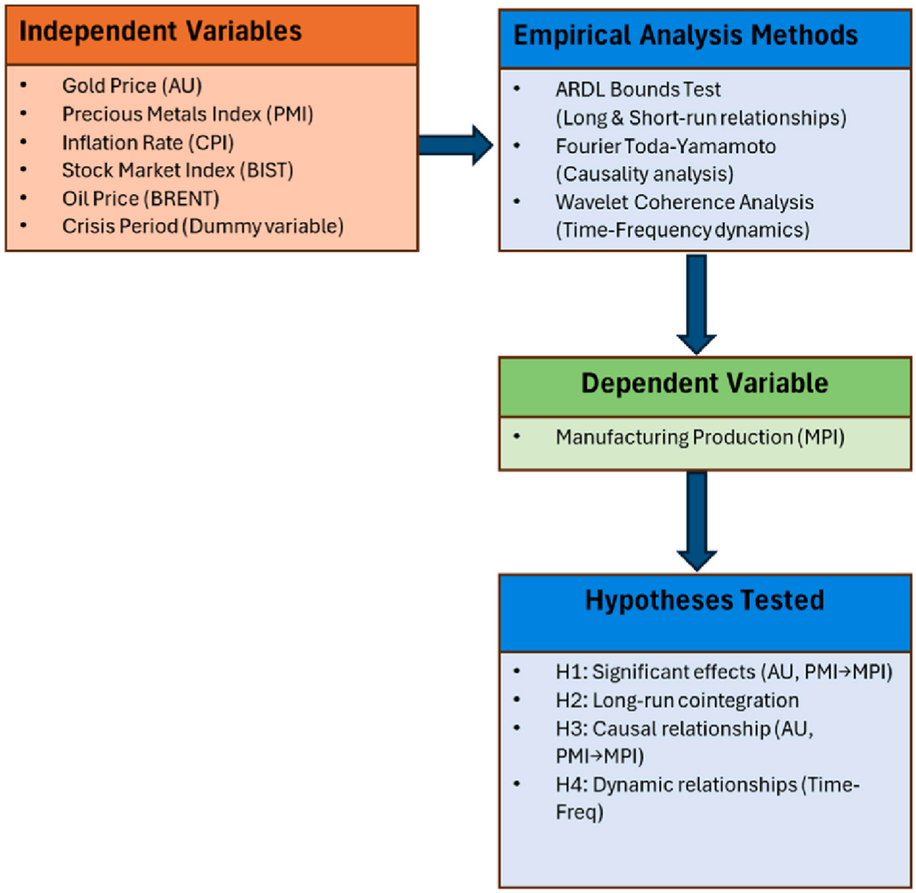


Fig. 2. Theoretical and empirical framework of the study.

Table 2
Fourier Toda Yamamoto causality tests results.

Causality	MPI→INDEPENDENT		INDEPENDENT→MPI		Results
	Wald Stat.	Prob Val.	Wald Stat.	Prob Val.	
DUMMY	39.800***	0.000	23.983***	0.000	MPI↔DUMMY
AU	0.112	0.738	4.048**	0.044	MPI←AU
BIST	6.552	0.364	2.208	0.900	MPI-BIST
BRENT	3.646	0.302	2.156	0.541	MPI-BRENT
CPI	3.081	0.214	0.580	0.748	MPI-CPI
PMI	9.407***	0.002	2.284	0.131	MPI→PMI

"period." Accordingly, the upper part of the graphs represents low-period (short-term, high-frequency) fluctuations, while the lower part represents high-period (long-term, low-frequency) fluctuations. Therefore, short-term relationships are evaluated in the upper part of the graphs, while long-term relationships are evaluated in the lower part.

The colors used in the graphs indicate the strength of the relationship between the variables. Tones closer to red indicate a strong relationship (high coherence) between two variables, while tones closer to blue indicate a weak or meaningless relationship. The thick black line on the graph delineates the statistically significant regions at the 5 % significance level. Additionally, the arrows in the graphs indicate the phase relationship between two variables and the direction of causality; if the arrows point to the right (→), there is a positive relationship between the

Table 3
ARDL bound test results.

Bounds	%10		%5		%1		Results
F Stat = 12.889	I (0)	I (1)	I (0)	I (1)	I (0)	I (1)	Cointegrated
	2.145	3.258	2.48	3.668	3.195	4.524	
Long Range Form							
	Coefficient		Std. Err.		t stat.		p val
AU	0.159318		0.042834		3.72		0.000
PMI	0.153261		0.065173		2.35		0.019
CPI	−0.56603		0.256096		−2.21		0.028
BIST	0.087258		0.04453		1.96		0.051
BRENT	0.136642		0.051393		2.66		0.008
Crisis	−0.43411		0.13868		−3.13		0.002
Diagnostic Tests							
Tests	Chi2		Df.		Prob. Val.		Results
White Test	1.6		1		0.2052		No heteroskedasticity
Breusch–Godfrey LM test	1.767		1		0.1838		No autocorrelation
Breusch–Pagan	0.43				0.5120		No heteroskedasticity

variables, while a leftward point (←) indicates a negative. If the arrows point upward (↑) or downward (↓), they indicate that one variable precedes or lags behind the other periodically. In this context, the results of the wavelet coherence analysis are presented in.

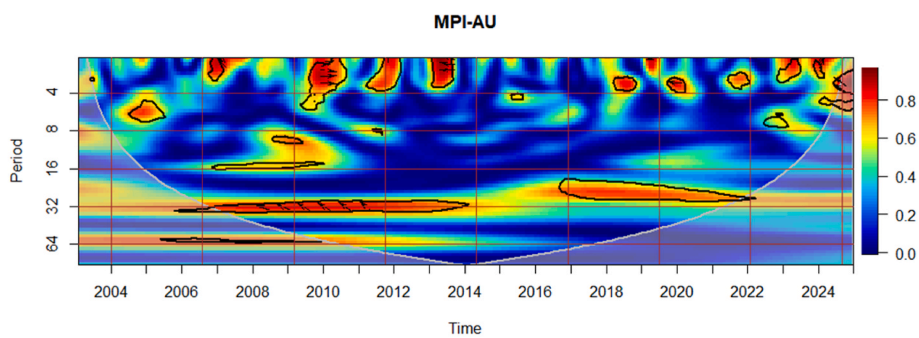
Within this framework, the wavelet consistency analysis results presented in Fig. 3 reveal the periodic and dynamic structure of the relationships between variables in both the time and frequency dimensions.

The results of the wavelet coherence analysis of the relationships between variables are shown in Fig. 3. When examining the results of the wavelet coherence analysis of the relationship between MPI and AU, it is understood that the two variables are generally weakly and periodically related. In particular, a positive relationship is observed in short-term (low-period, around 4–8), regions between 2009 and 2010, but this relationship has been replaced by a negative relationship in short-term regions in 2013. In long-term regions characterized by high frequency (32–64 range), a complex structure was observed between 2005 and 2014, with both positive and negative relationships coexisting. However, these relationships were relatively weak and short-lived, failing to form a stable relationship pattern. In conclusion, it is possible to state that there is no clear, strong, and stable relationship between the MPI and gold prices (AU). The findings indicate that the relationship between the two variables is periodic, short-term, and of low intensity.

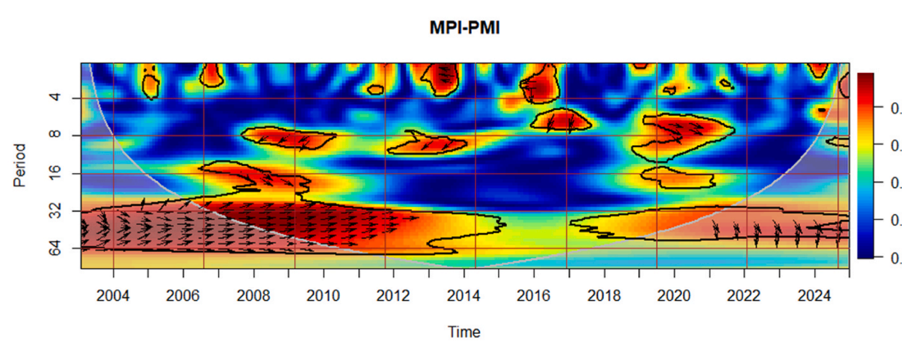
When examining the results of the wavelet coherence analysis of the relationship between MPI and PMI variables, a strong and continuous positive relationship is observed in the long-term (high-period, 32–64 range) regions between 2004 and 2015. The red areas and right-pointing arrows in this period indicate that the relationship is positive and synchronous. Towards the end of the analysis period (after 2020), a complex structure is observed in the long and medium-term regions (16–64 period), where both positive and negative relationships coexist. During this period, the strength of the relationship appears to have weakened significantly and become unstable. In conclusion, while a long-term and strong positive relationship between MPI and PMI was clearly observed in the first half of the analysis period. The strength of the relationship has weakened, and its direction has become more complex in recent years. This indicates that the relationship between the two variables has lost its stability in recent years.

When examining the results of the wavelet coherence analysis of the relationship between the proxy variable representing the crisis period

(**3**. A)



(3. B)



(3. C)

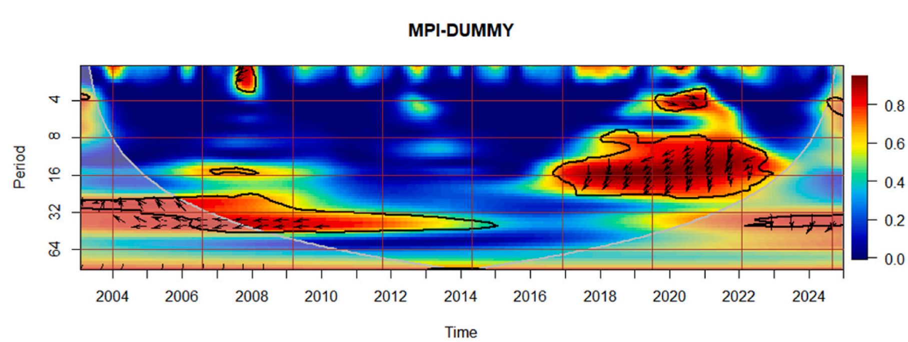
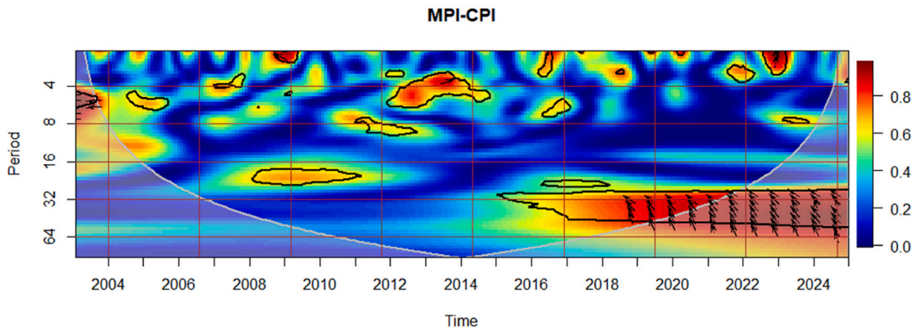
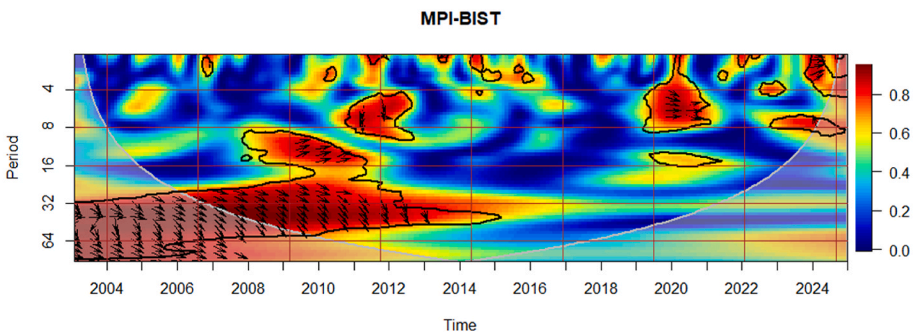


Fig. 3. Graphs for wavelet coherence analysis.

(3. D)



(3. E)



(3. F)

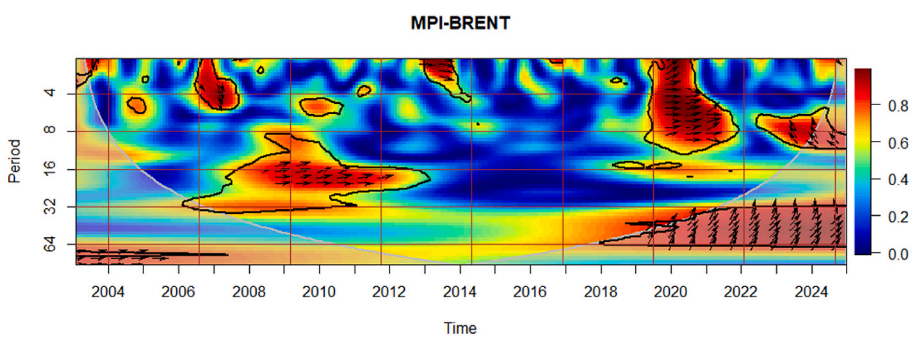


Fig. 3. (*continued*).

and the MPI, a significant and continuous negative relationship is observed in most of the analysis period, especially in the long-term (high-period, 32 and above, and medium-term (16–32 periods) regions. The areas close to red, and the arrows mostly pointing to the left, indicate the strength and direction of this negative relationship. Between 2014 and 2016, however, no significant relationship was detected in either the medium- or long-term areas. In all other periods, especially during times of intense crisis, the negative relationship continued steadily. In conclusion, there is a significant and stable negative relationship between the MPI and the dummy variable representing the crisis period in the medium and long term. This relationship only weakens during the 2014–2016 period.

When examining the wavelet coherence analysis results for the relationship between MPI and CPI, a strong and significant relationship is observed, particularly towards the end of the analysis period (after 2018) in the long-term (32 periods and above) region. The red colors in this period indicate that the relationship has high coherence values. However, the arrows in the same region being directed upward and slightly to the left indicates that the relationship is not fully synchronous, and that the movements in the MPI variable occur before those in the CPI variable, thereby demonstrating that MPI serves as a leading indicator for CPI. In the short term (low-period, 4–8 range) regions, however, there are occasionally meaningful and positive, but weaker and more short-term relationships. This indicates that the relationship between MPI and CPI is not stable in the short term but becomes more pronounced and stable in the long term. In conclusion, while the Wavelet coherence analysis indicates the existence of a strong and long-term relationship between MPI and CPI, it also highlights the need to evaluate the relationship in terms of its causality or influence direction. In this context, MPI can be used as a long-term leading indicator for developments in the CPI variable.

The results of the wavelet coherence analysis of the relationship between MPI and BIST variables are shown in Fig. 3 (3. E). At the beginning of the analysis period (2003–2015), a strong and stable positive relationship is observed in the long-term (high-period, 32 years and above) region. The density of the red areas and the arrows pointing to the right during this period indicate the existence of a meaningful and simultaneous positive relationship between the two variables. Towards the end of the analysis period, a positive relationship is observed in the short-term regions, those with low-periods within the 4–8 range, i.e., the upper part of the graph. However, this relationship is more limited and short-term compared to its long-term effects. Overall, it is observed that the relationship between MPI and BIST is stronger and more stable at the beginning of the analysis period and limited towards the end of the period, with stability being more evident in the long term as opposed to the short term.

The results of the wavelet coherence analysis of the relationship between MPI and Brent oil prices are presented in Fig. 3 (3.F). The graph reveals a generally positive and significant relationship between the two variables. In particular, between 2007 and 2012, there was a strong and positive medium-term relationship (8–16 periods) in the areas. During this period, the red regions and arrows pointing to the right (positive and synchronous) indicate that the two variables move together. However, between 2014 and 2018, no significant relationship was detected in short-, medium-, or long-term intervals; during this period, the coherence values were low, and the colors were closer to blue. As the analysis period nears its end (especially after 2020), a positive relationship is again observed in the long term (high-period, 32 and above) areas. The fact that the arrows are mostly directed to the right and slightly upward suggests that this relationship is generally positive and that Brent's movements are partially followed by MPI. In conclusion, while the relationship between MPI and Brent oil prices exhibits temporal variations, it is generally positive and significant; although it weakened between 2014 and 2018, it strengthened in both the medium and long term at the beginning and end of the analysis period.

When the results are evaluated collectively, the ARDL cointegration test confirms hypothesis H2, as the F-statistic exceeds the critical value at the 1 % significance level thus, a significant long-term cointegration relationship exists between precious metal prices (AU and PMI) and the Manufacturing Production Index (MPI). The long-term coefficient estimations, indicate that gold prices (AU) positively and significantly influence MPI (β AU $= 0.159$, $p < 0.01$), and similarly, PMI also has a positive and significant impact on MPI (β PMI $= 0.153$, $p < 0.05$). These results fully confirm hypothesis H1. Conversely, inflation (CPI), and the crisis-period dummy variable negatively impact MPI, indicating that inflationary pressures and crisis periods constrain manufacturing production in Türkiye.

The Fourier-Toda Yamamoto causality tests reveal a unidirectional causal relationship from AU to MPI (Wald $= 4.048$, $p < 0.05$), demonstrating that gold price shocks significantly affect manufacturing production. However, no direct causality was observed from PMI to MPI; instead, a reverse causality from MPI to PMI emerged. Thus, these findings only partially confirm hypothesis H3, highlighting that while gold price shocks significantly influence production, the composite precious metals index (PMI) itself does not have a similarly direct causal effect.

Wavelet Transform Coherence (WTC) analysis provides further insights by dynamically illustrating temporal and cyclical fluctuations in relationships among variables. Specifically, the AU–MPI relationship, although generally weak and periodic, showed brief positive interactions in 2009–2010, negative interactions in 2013, and more sustained positive interactions, towards the end of the analysis period. In contrast, the MPI–PMI relationship was consistently strong and positive during 2004–2015 but demonstrated increasing complexity and weakening coherence after 2020. Additionally, a persistent negative relationship between MPI and crisis periods was confirmed. The MPI–CPI relationship was strong and positive over the long term, with MPI serving as a leading indicator for CPI, especially after 2018. Relationships between MPI–BIST and MPI–Brent also displayed significant positive correlations, with variations evident across different periods. These dynamic findings fully support hypothesis H4.

Collectively, these empirical results provide evidence supporting and complementing prior studies in the literature. The positive long-term impact of gold prices aligns with findings by Bildirici et al. (2016) and Bildirici and Ozaksoy Sonustun (2018), suggesting precious metals stimulate economic activity under certain conditions. However, this contrasts partially with Baur and McDermott (2010), who emphasize gold primarily as a safe-haven asset during crises. Contrary to Sari et al. (2010), who reported stronger short-term relationships, this study identifies more pronounced long-term relationships, likely due to methodological distinctions. The study aligns with Gençyürek and Ekinci (2023) in underscoring the significance of precious metals' significance for risk management but highlights temporal variability in PMI's influence. The negative impacts of inflation and crisis periods are consistent with broader macroeconomic cycle models (Boakye et al., 2024; Şen et al., 2024). Additionally, findings supporting temporal variability in MPI–BIST and MPI–Brent relationships resonate with Tursoy and Faisal (2018), emphasizing the necessity of dynamic analytical approaches. Finally, the importance of precious metals markets for local economic indicators is consistent with Yurdakul and Sefa (2015).

Overall, this comprehensive analysis contributes significantly to the literature by explicitly testing key hypotheses (H1–H4), highlighting the dynamic and cyclical complexity of precious metals relationships with manufacturing production, and providing empirical and methodological insights relevant for policymakers.

5. Conclusion and policy implications

This study comprehensively analyzes the short- and long-term relationships between the manufacturing production index (MPI) and precious metal markets in Türkiye, covering the period from 2003M1–2025M2, and is accompanied by macroeconomic and financial indicators. The limited number of studies in the literature addressing the direct impact of precious metal prices on production constitutes the fundamental originality of this study. The advanced econometric methods used in the research, such as Fourier-ARDL cointegration analysis, Fourier-Toda Yamamoto causality test, and Wavelet Coherence Analysis (WTC), provide innovative methodological insights into the results.

According to the analysis results, there is a stable long-term cointegration relationship between the gold price (AU) and the composite precious metals index (PMI), as well as manufacturing industry production (MPI). In the ARDL analysis, AU and PMI were found to have positive effects on MPI, while inflation (CPI) and the crisis period dummy variable had negative and significant effects. These findings indicate that precious metals should be evaluated not only as financial assets but also as economic factors that directly affect production processes.

The results of the Fourier-Toda Yamamoto causality test reveal that gold price shocks have a unidirectional effect on production and that crisis periods in particular, have a reciprocal effect on production. This situation shows that the effect of precious metal prices on the production in the Turkish economy has different dynamics depending on the period.

Wavelet coherence analysis has determined that the relationships have a dynamic structure in terms of time and frequency. It has been observed that the AU-MPI relationship changes periodically, while the PMI-MPI relationship exhibits a strong positive structure for most of the analysis period but has become complex in recent years. In the MPI-CPI relationship, it was observed that MPI acts as a leading indicator for CPI. Additionally, a consistent and strong negative relationship was identified between MPI and crisis periods. It was also understood that the relationships between Borsa Istanbul (BIST), Brent oil prices, and MPI exhibit periodic variability and are generally positive.

The findings contain both supportive and complementary elements to previous studies. Notably, our results suggest that gold and other precious metals have begun to transcend their traditional role as mere "safe havens," instead acting as potential drivers of manufacturing growth in Türkiye. While this positive role of gold prices in economic activities aligns with Bildirici et al. (2016) and Bildirici and Ozaksoy Sonustun (2018), it partially diverges from the findings of Baur and McDermott (2010), who conceptualize gold primarily as a "safe haven" during crisis periods. Contrary to Sari et al. (2010), who argue that short-term relationships are strong while long-term relationships are weak, this study finds that long-term relationships are more pronounced and stable. Furthermore, the importance of precious metals for risk management, as highlighted by Gençyürek and Ekinci (2023), is supported, though the effect of the PMI composite index may vary over time. Finally, the negative effects of inflation and crisis periods on manufacturing production are consistent with the broader literature.

The theoretical contribution of this study lies in illuminating the evolving role of precious metals, from safe-haven assets to active industrial drivers, by clarifying the transmission mechanisms to the manufacturing sector at both national and global levels. Additionally, the study methodologically reveals the dynamic and cyclical nature of these relationships using advanced techniques such as Fourier and wavelet analyses. In terms of policy implications, the main emphasis is that shocks in precious metal prices can have persistent effects on the real sector, warranting careful consideration in monetary policy. Particularly during crisis periods, developing supportive industrial policies, implementing cost-reducing measures, and promoting risk protection mechanisms becomes critically important for sustaining manufacturing growth.

Among the limitations of the study are that the analysis period ends in February 2025, meaning recent developments are not fully reflected, and the metals comprising the composite index have not been examined separately. Future research should separately evaluate the effects of these metals, expand the model to include additional macro-financial variables such as money supply, real interest rates, and external demand, and repeat the analyses using high-frequency data.

In conclusion, this study provides important empirical, methodological, and policy contributions to the literature by analyzing the effects of precious metal markets, particularly gold, on the production sector in the Turkish economy using innovative and comprehensive methods.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.bir.2025.09.005.

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