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Roling-window bounds testing approach to analyze the relationship between oil prices and metal prices

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ABSTRACT

This paper is to find how the existence of a long-run relationship between oil prices and metals prices evolved for the time from January 1979 to December 2017. The rolling-window autoregressive lag modeling (RARDL) testing approach of cointegration has been introduced and applied to assess the long-run relationship considering four rolling windows of 5, 10, 15, and 20 years. The empirical evidence concludes that for a small rolling window of 5 years, there is no evidence of the long-run relationship between oil prices and metals prices, i.e. gold, platinum, and silver. However, there is a long-run relationship between oil prices and steel prices from December 2003 to December 2014. At larger rolling windows of 10, 15 and 20 years, oil prices and gold prices are not cointegrated; however, steel, silver, and platinum have a long-run relationship with oil prices in different periods.

1. Introduction

Oil is considered to be the most strategic commodity, an indicator of the price level of many other commodities, and the most common input for the production process. Similarly, precious metals (e.g. gold, silver, copper etc.) serve as a means of the store of value, particularly during periods of heightened economic and political uncertainty. These metals are considered a safe haven against extreme fluctuations in other commodity prices, a hedge against inflation, and an input in the production process. Metals, *especially gold and silver*, have traditionally been viewed as investment vehicles, whereas copper, platinum, and palladium, as well as oil, have conventionally been viewed as inputs for production process. However, investment demand for oil, copper, platinum, and palladium, and industry demand for gold and silver is increasing due to the financialization of commodities and their diversified industrial use (Lau et al., 2017). Since, oil and precious metals are somewhat linked to production, output, consumer and producer prices, while markets for such commodities are expected to be linked. Various studies such as Baffes (2007), Bildirici and Turkmen (2015), Pindyck and Rotemberg (1990), Kilian and Park (2009), Lescaroux (2009), Turhan et al. (2014), Zhang and Wei (2010) exhibit a strong association between oil prices and metals prices. Bouri et al. (2017a) concluded that gold and oil prices have a long run relationship with indian stock market and there is evidence of nonloinear causality. Moreover, Bouri et al. (2017b) found out that the corn market is dominated by the crude oil market. Similarly, Dutta et al. (2019) reported the presence of bidirectional causality between crude oil and precious metals markets was found. Nevertheless, what is the true nature of the relationship, linear or non-linear, is yet debatable, where one school of researchers (e.g. Zhang & Wei, 2010) claim a linear relationship between oil prices and metals, others (e.g. Bildirici & Turkmen, 2015) argue a non-linear relationship between commodity variables. Further, the relationship between prices of oil and the precious metal is also found to be different in the context of the regime (regime dependent and regime independent). For instance, the studies of Balcilar et al. (2015), Bhar and Hammoudeh (2011), Ewing and Malik (2013), Lau et al. (2017), Turhan et al. (2014) among others, in general, show that regime-dependent model can capture the relationship between oil and precious metal prices better than regime-independent models. Similarly, Bhar and Hammoudeh (2011) and Balcilar et al. (2015) report a more pronounced impact of oil prices to shock on precious metal prices in the high-volatility regime.

Apparently, ambivalent results are attributing to the methods applied for investigating this association. It is argued that the equilibrium relationship between oil prices and precious metal prices

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are subject to frequent changes mainly due to financial crises, restricted supply, and demand shocks, among others (Balcilar et al., 2015). As a result, most of the contemporary methodologies used for analyzing oil-metal associations tend to be over-restrictive and may suffer from model misspecification. This phenomenon has induced renewed interest among academics, policymakers, and investors to investigate the nature and extent of this co-movement. Further, in recent years increasing speculative activities in emerging economies lead to more uncertainty and volatility in the commodity markets. The volatility can affect the decision of investors for portfolio allocation and value-at-risk management, as well as the industrial production of manufacturers and, therefore, the economic growth pattern of nations. As a result, the correct modeling of volatility in metal markets is a crucial issue, which on one side, increases the ability to generate more accurate out-of-sample forecasting of prices for policy-makers, and on another side facilitates value-at-risk management strategies for financial traders (Behmiri & Manera, 2015).

It has been observed in the empirical literature that the evidence of the existence or absence of cointegration may be influenced by mostly the parameter inconstancy. However, the simple frequently used cointegration techniques like ARDL (Pesaran et al., 2001), Johansen (Johansen & Juselius, 1990) etc. consider the constancy of parameters and estimate a single cointegrating vector throughout the whole time series. Therefore, if the cointegrating vector is changing with time i.e., parameters are unstable, then these frequently applied techniques are not able to capture it and they may lead to a wrong conclusion. This fact has been discussed in numerous studies like (Asai et al., 2019, 2020; Aysan et al., 2021 and Gkillas et al., 2020). Hence a technique is required which may take the parameter inconstancy into consideration and try to test for the absence or existence of cointegration with possibly changing cointegrating vector(s). For this purpose, we are introducing a newly developed technique, i.e. Rolling-window Autoregressive Distributed Lag Modeling (RARDL) approach of cointegration. The RARDL tests the existence of cointegration, keeping in consideration that the cointegrating vector may possibly be changing with time, and if the cointegration exists, then it gives an Error Correction Model (ECM) with inconstant parameters. If the cointegrating vector is unique and constant throughout the time span, then even RARDL does show this result strongly. In doing so, this study contributes to the existing literature by two folds: (i); It investigates the relationship between oil prices and precious metal prices for the period of 1979–2017 using month frequency data. (ii), This study introduces a newly developed approach, i.e. rolling-window autoregressive lag modeling *(*RARDL*)* free from the weaknesses of contemporary approaches, to model the oil-metal relationship. Since our sample period corresponds to several major economic, financial and political events that can lead to a regime dependent relationship between oil and precious metal prices, we provide more realistic and reliable findings derived from RARDL as opposed to other conventional approaches. Although the interconnectedness of oil and precious metal prices has been examined by some studies using regime-dependent models, the use of RARDL was beyond the scope of these studies. Our empirical results reveal that association between oil prices and metal prices is window size and regime dependent. It is noted that there is no long run cointegration relationship between oil prices and metals prices, i.e. gold, platinum, and silver using a small rolling window of 5 years.

2. Literature review

The literature on the interaction between oil and precious metal prices primarily highlights three significant association transmissions between oil and metal prices: First, oil-metal prices correlational association (Baffes, 2007), second, oil-metal prices long term causal association (Sari et al., 2010; Zhang & Wei, 2010), and third, the impact of oil prices shocks on metal prices (Hammoudeh & Yuan, 2008). Researchers such as Baffes (2007), Pindyck and Rotemberg (1990), study the correlational association between oil-metal prices and find a direct correlation between oil prices and commodity prices. This relationship can be found stable in all the studies using varying frequencies of data, i.e. daily weekly, monthly, and annually. Notably, Baffes (2007) exhibits that shock in oil prices is instrumental in bringing major shocks in metal prices. Similarly, Lescaroux (2009) explains that a high level of correlation between oil and metal prices can be attributed to the shocks in market forces. Supporting the findings of previous studies, Turhan et al. (2014) argue that positive and significant correlation between oil and metal prices (specifically gold) tends to increase over time. Nevertheless, some of the studies (e.g. Sari et al., 2010; Zhang & Wei, 2010) find a fragile, null, or unidirectional association between oil and metal prices. For example, Zhang and Wei (2010) show a one-way relationship from oil to metal prices, whereas Sari et al. (2010) exhibit a highly insignificant bidirectional association between oil and metal prices. From the time perspective, the majority of studies such as Sari et al. (2010), Soytas et al. (2009) denote the significant influence of oil prices on metals in short run and long run.

However, with regard to the time horizon, studies found mixed results for the impact of oil prices on metal in the short run and long run. For example, Soytas et al. (2009), on one hand, note an important influence of oil prices on metals (gold and silver) in the short run. Whereas, researchers like Jain and Ghosh (2013), Sari et al. (2010), on other hand, found an insignificant association between oil and metal prices in the long run. Further, Chang et al. (2013) find no association between oil and metal (gold) prices in the short-run and long run. A scant review of the literature reveals that the majority of the studies on the oil-metal priced dyad find their cointegration in short-run but not in long run. Interestingly, a few researchers like Bildirici and Turkmen (2015) show a quadratic association between oil-metal prices. Bildirici and Turkmen (2015), in this regard, denote a non-linear effect of change in oil prices on metal. However, these findings show a two-way relationship in contrast to Sari et al. (2010), who found a one-way association (from oil to gold) between oil and metal prices. These ambivalent findings, *interalia,* may be due to the heterogeneity in techniques used for analyzing this dyad.

Further, it is also worth mentioning that the majority of the above-discussed studies investigate the oil-metal prices association by employing "regime independent models." Whereas it is a highly renowned fact that, owing to the various events like financial crisis, economic recession etc., the majority of financial and economic longitudinal data depict the structural breaks. For example, Kim et al. (2008), using such data in independent regime models and employing traditional OLS for analysis may give unstable parameters. In such a context, employing the models with "regime-switching" may have better performance (Lee & Chen, 2006). For example, Bhar and Hammoudeh (2011) by employing the VAR model, found a significant regime dependent association between oil prices and metal (gold, silver, and copper) prices. They also denoted a higher impact of oil return on metal's returns in the period of higher volatility regime. Likewise, Balcilar et al. (2015) depict a significant positive impact of oil prices shocks on metal (platinum, gold) prices. In congruence with Balcilar et al. (2015), Lau et al. (2017), using regime dependent co-integration, found cointegration between oil prices and metal prices in the presence of peculiar structural breaks. Previously the congruent findings were also shown by Ewing and Malik (2013) and Turhan et al. (2014).

In condensed form, reviewing the literature reveals that oil and metal prices can be linked through *volatility dependences, economic transmission, market efficiency, and price co-movements.* However, it can be noted that irrespective of a plethora of literary work in oil-metal prices nexus, it is hard to find any consensus among the studies on this association. Most of the results are of mixed nature and, in some cases, extremely contradictory. These ambivalent findings, *interalia,* may be due to the heterogeneity in techniques used for analyzing this dyad. In order to overcome the weaknesses of previous methods, a rolling window ARDL bounds test has been applied.

3. Methodological framework

The existence of long-run relationship between oil prices and metal prices i.e. gold, platinum, silver, and steel, is investigated using ARDL bounds testing approach of cointegration for monthly data from January 1979 to December 2017. The ARDL bounds testing approach has some advantages, as it does not need pretesting for unit root. Furthermore, as it uses the ECM for testing the cointegration, so if there is cointegration, then we do not need to estimate an ECM[1] . Moreover, many studies like (Khan & Khan, 2018) and Khan et al. (2019) have emphasized that the ARDL test is the most theoretically sound cointegration test compare to other tests in the class of single-equation cointegration tests. The ARDL test considers all possible five different models in economics. Keeping above caveats, a rolling-window ARDL bounds test has been applied using simulated critical values, considering four different rolling windows of 5, 10, 15 and 20 years.

3.1. Auto-Regressive Distributed Lag Modeling (ARDL) or bounds test

The ARDL bounds test of cointegration was developed by Pesaran et al. (2001). The bounds test estimates the single equation Error Correction Model (ECM) i.e.

$$\Delta y_t = c_0 + c_1 t + \phi\left(\pi_0 + \pi_1 t + \alpha y_{t-1} + \beta X_{t-1}\right) + \sum_{i=1}^{p}\gamma_i \Delta y_{t-i} + \sum_{i=0}^{p}\delta_i \Delta X_{t-i} + \varepsilon_t \quad (1)$$

y_t is a $T \times 1$ vector of endogenous/dependent variable, X_t is a $T \times k$ vector of k regressors i.e. $(x_{1t}, x_{2t}, - - - - - - - x_{kt})$, ε_t is a $T \times 1$ vector of random errors and p is the maximum number of lags for y_t and X_t. The value of p can differ for y_t and X_t, however, usually, it is taken the same. There are four parameters of interest i.e. c_0 the un-restricted intercept, c_1 the un-restricted linear time trend, π_0 the restricted intercept, and π_1 the restricted linear time trend. Five different models were discussed by Pesaran et al. (2001), and these models are given below:

Model 1 (M1): No intercept, No Trend:

For M1, $c_0 = c_1 = \pi_0 = \pi_1 = 0$ and the ECM in equation-1 becomes

$$\Delta y_t = \phi\left(\alpha y_{t-1} + \beta X_{t-1}\right) + \sum_{i=1}^{p}\gamma_i \Delta y_{t-i} + \sum_{i=0}^{p}\delta_i \Delta X_{t-i} + \varepsilon_t \quad (2)$$

Model 2 (M2): Restricted intercept, No Trend:

For M2 $c_0 = c_1 = \pi_1 = 0$ and the ECM in equation-1 becomes

$$\Delta y_t = \phi\left(\pi_0 + \alpha y_{t-1} + \beta X_{t-1}\right) + \sum_{i=1}^{p}\gamma_i \Delta y_{t-i} + \sum_{i=0}^{p}\delta_i \Delta X_{t-i} + \varepsilon_t \quad (3)$$

Model 3 (M3): Un-restricted Intercept, No Trends:

For M3 $c_1 = \pi_0 = \pi_1 = 0$ and the ECM in equation-1 becomes

$$\Delta y_t = c_0 + \phi\left(\alpha y_{t-1} + \beta X_{t-1}\right) + \sum_{i=1}^{p}\gamma_i \Delta y_{t-i} + \sum_{i=0}^{p}\delta_i \Delta X_{t-i} + \varepsilon_t \quad (4)$$

Model 4 (M4): Un-restricted Intercept, Restricted Trends:

For M4 $c_1 = \pi_0 = 0$ and the ECM in equation-1 becomes

$$\Delta y_t = c_0 + \phi\left(\pi_1 t + \alpha y_{t-1} + \beta X_{t-1}\right) + \sum_{i=1}^{p}\gamma_i \Delta y_{t-i} + \sum_{i=0}^{p}\delta_i \Delta X_{t-i} + \varepsilon_t \quad (5)$$

Model 5 (M5): Un-restricted Intercept, Un-restricted Trend:

For M5 $\pi_0 = \pi_1 = 0$ and the ECM in equation-1 becomes

$$\Delta y_t = c_0 + c_1 t + \phi\left(\alpha y_{t-1} + \beta X_{t-1}\right) + \sum_{i=1}^{p}\gamma_i \Delta y_{t-i} + \sum_{i=0}^{p}\delta_i \Delta X_{t-i} + \varepsilon_t \quad (6)$$

For the testing of existence of long run relationship, the null hypothesis of no cointegration i.e.

$H_0 : \varphi = 0$ (*No Long run relationship*)

Is tested against the alternative hypothesis of cointegration i.e.

$H_A : \varphi \neq 0$ (*Long run relationship exists*)

Pesaran et al. (2001) used the standard $F - test$ for linear restrictions to test H_0 i.e.

$$F = \frac{(RSSR - RSSU)/q}{RSSU/(T-k)}$$

Where *RSSR* is the Residual Sum of Squares for Restricted Regression, *RSSU* is the Residual Sum of Squares for Unrestricted Regression, q is the number of restrictions and k is the total number of parameters estimated. Two critical values of $F - stat$ were obtained; one was named as lower bound, denoted as F_{LB} and it was the $100(1-\alpha)th$ percentile of F when X_t are generated as $I(0)$ i.e. integrated of order zero. The other was named as upper bound, denoted as F_{UB} and it was the $100(1-\alpha)th$ percentile of F when X_t are generated as $I(1)$ i.e. integrated of order one. The α is the assumed significance level. The null hypothesis of no cointegration is rejected when $F \geq F_{UB}$ and it is concluded that there is a long run relationship between y_t and X_t. If $F \leq F_{LB}$, then it is concluded that there is no long run relationship between y_t and X_t. However, if $F_{LB} < F < F_{UB}$, then it is concluded that the test is inconclusive.

3.2. Simulated critical values

Pesaran et al. (2001) generated two bounds of asymptotic critical values, as they used a sample size of 1000. It is pointed out in the literature by many studies like Khan and Khan (2018), Khan and Zaman (2017) and many more that the problem of over rejection arises when asymptotic critical values are used. Therefore, in this paper, simulated critical values are estimated and then used for testing, taking four rolling-windows (RWs) of size 60, 120, 180, and 240. For this purpose, the same data generating process of Pesaran et al. (2001) is used, with a maximum lag length of 5 and BIC or

[1] The rest of cointegration tests except system based tests, first check for cointegration and then estimate an ECM. However, their test equation for cointegration testing is different than ECM. ARDL uses the same ECM for cointegration testing and after getting the cointegration the same test equation as a model.

SIC is used for automatic model selection. Moreover, the first 300 values generated by the data generating process are not considered to settle the initial value problem. A total of 50,000 simulations have been carried out to obtain the simulated critical values.

3.3. The Rolling-Window ARDL(RARDL) bounds testing approach to cointegration

The Rolling Window Cointegration tests other than ARDL have already been used in the literature in a number of studies like (Kutan & Zhou, 2003; Mylonidis & Kollias, 2010) and (Demirer et al., 2019). The ARDL test assumes that the cointegrating vector is unchanged for the whole time series, and the parameters are constant. However, in reality, it may not be the case, then the ARDL will lead us to a wrong conclusion. Therefore, this assumption of constant cointegrating vector(s) and parameters stability must be relaxed to capture the true nature of the relationship. This can be achieved by RARDL, as it will relax the said assumption and even if the assumption is true then it will give a strong evidence for that. For a total sample size of T, let the size of rolling-window is T_R. The RARDL bounds test is applied using the following steps:

1 The ARDL bounds test is applied on first T_R observations of X_t and Y_t for $t = 1, 2, \ldots.., T_R$. $F - stat$, p-value and other statistics of interest are noted.
2 Then again an ARDL bounds test is applied by excluding first observations and including one observation more i.e. $(T_R + 1)th$ of X_t and Y_t i.e. The ARDL bounds test is estimated for $t = 2, 3, \ldots.., T_R + 1$ observations of X_t and Y_t. $F - stat$, p-value and other statistics of interest are again noted.
3 The step 2 is repeated until the last observations T are included. Therefore, there will be $(T - T_R + 1)$ ARDL bounds tests of cointegration and their relative statistics.

The RARDL is quite different than the bootstarp ARDL used by Anser et al. (2021) as the later assumes the estimates as population papramters and try to find the critical value. However, the RARDL assumes the same hypothetical data generation as was assumed by the novel paper by Pesaran et al. (2001). In this paper, four rolling windows i.e. $T_R = 60,\ 120,\ 180\, and\, 240$ are taken. These four rolling windows represent four different spans of time i.e., 5, 10, 15, and 20 years.

4. Empirical results and their discussion

The simulated critical bounds of ARDL bounds $F - stat$ for four rolling windows are given in Table 1. These bounds are used for decision in the rolling-window ARDL bounds tests. It can be observed that when the rolling window size is small i.e. 60, then the bounds in Table 1 are much greater than the bounds specified by Pesaran et al. (2001). However, as the size of the rolling window increases i.e. from 60 to 120, then 180 and at last 240, bounds in Table 1 converge to the bounds specified by Pesaran et al. (2001).

For the first rolling-window of size $T_R = 60$, RARDL bounds test has been applied 409 times, giving $F - stats$, their p-values, and other related statistics from December 1983 to December 2017. The detailed results for all five models of each four pairs i.e. (gold, oil), (platinum, oil), (silver, oil), and (steel, oil) are given in Appendix (Table A1 provided online). The Model 5 (M5) of RARDL bounds test is more suitable here because it is supported by economic theory. Therefore, for this model M5, p-values of $F - stat$ when $X_t \sim I(1)$, for four pairs of variables are plotted against time in Fig. 1.

It is evident from Fig. 1 that there is very much little evidence about the existence of long-run relationship between gold and oil as cointegration between the variables seems very rare. The same is the case of long run relationship between platinum and oil, and between silver and oil. However, between steel and oil, there is strong evidence of the existence of a consistent long run relationship from December 2003 to December 2014 with two or three spikes in p-values. Moving towards the second RW of size $T_R = 120$ i.e. 10 years, the rolling-window ARDL bounds test has been carried out for 349 RWs. The detailed results for all five models of ARDL bounds test are given in Appendix (Table A2 provided online). However, M5's p-values of $F - stat$ for four pairs of variables are plotted against time, ranging from December 1988 to December 2017, in Fig. 2. It is clear that there is no evidence of long-run relationship between gold and oil at 1% and 5% levels of significance. However, evidence of long-run relationship between gold and oil exists for one or two RWs at 10 % level of significance, which is very rare as there are a total 349 RWS. For the second pair i.e. platinum and oil, the long run relationship exists for three different periods of time. There is evidence of long run relationship from November 1979 to June 1996 with two or three spikes in p-values, then from September 1998 to August 2013 with no spikes in p-values and from January 2005 to December 2017 with two spikes in p-values.

For the third pair of silver and oil, there are very rare evidence of long run relationship. However, for the last and fourth pairs of steel and oil, there is very strong consistent evidence of the existence of a long run relationship from December 1998 to December 2017 with three spikes in p-values. For the majority of time period from December 1998 to December 2017, cointegration exists at 1% level of significance, which is evidence of a very strong long-run relationship. Moving towards the third rolling window of size $T_R = 180$, covering a span of 15 years, the detailed results listing F-statistic of all five models of ARDL bounds test carried out 289 times (289 RWs) for four pairs of variables are listed in Appendix (Table A3 provided online). However, the p-values of the most theoretically supported model i.e. M5 are plotted against time, ranging from December 1993 to December 2017, in Fig. 3. Very few evidence of existence of long run relationship between gold and oil are observed and also these evidences are not consistent. There is an evidence of cointegration between gold and oil from January 1980 to January 1995 at 10 % level of significance and then there is evidence of cointegration between the said two variables from July 1980 to December 1995 with one spike in p-values at 5% level of significance. Other than these two periods, four or five times, there is evidence of cointegration, which has no worth mentioning here. The second pair of platinum and oil has very strong and consistent evidences of the existence of long run relationship for two long time periods (from November 1979 to May 2000 with one spike in p-value and from October 1993 to March 2015 with no spikes in p-values) and one brief time period (March 1993 to March 2008). For the third pair of silver and oil, there are evidences of the existence of long run relationship for five different time periods. From these five time periods, two are relatively long (from January 1979 to October 1994 with no spikes in p-values and May 1987 to December 2003 with one spike in p-values) and three are relatively short (from March 1980 to March 1995, from August 1980 to December 1995 and from May 1983 August 1998). Other than these five there are some other evidences of long run relationships, but they are not worth mentioning here. For the last pair of steel and oil, there is a very strong and consistent evidence of existence of long run relationship from July 1993 to December 2017, mostly at 1% level of significance.

Moving towards the fourth and last size of rolling-window i.e. $T_R = 240$, covering a span of 20 years, the detailed F-statistics (for 229 RWs) of all five models for all four pairs of variables are listed in Appendix (Table A4 provided online). The p-values for Model 5 (M5) are plotted against time, ranging from December 1998 to December 2017 in Fig. 4. The long-run relationship between gold and oil exists for two relatively longer time periods (from January

Table 1
Simulated Critical Bounds for F-Test.

T_R	$\alpha = 0.01$		$\alpha = 0.05$		$\alpha = 0.1$	
	$X_t \sim I(0)$ F_{LB}	$X_t \sim I(1)$ F_{UB}	$X_t \sim I(0)$ F_{LB}	$X_t \sim I(1)$ F_{UB}	$X_t \sim I(0)$ F_{LB}	$X_t \sim I(1)$ F_{UB}
Model 1						
60	6.0145	6.8505	3.6934	4.4652	2.7139	3.4630
120	5.2850	6.1035	3.3617	4.1229	2.5811	3.3266
180	5.2367	5.9934	3.3739	4.0438	2.5406	3.2685
240	4.9344	5.9790	3.1613	4.1203	2.4786	3.2781
Model 2						
60	8.4838	9.4572	5.5055	6.4726	4.4164	5.2432
120	7.3425	8.4583	5.2234	5.9668	4.2122	4.9848
180	7.0482	8.1909	5.0666	5.9344	4.1508	4.8941
240	7.0287	8.1270	5.1751	5.8301	4.2486	4.8515
Model 3						
60	8.0867	9.4199	5.5531	6.5602	4.4145	5.1901
120	7.2621	8.3068	5.2086	6.0142	4.2017	4.9598
180	7.3770	8.1172	5.0625	5.7769	4.1675	4.7985
240	7.0447	7.9403	5.0597	5.7449	4.0882	4.8092
Model 4						
60	7.1195	8.9295	4.4909	6.1078	3.4036	4.7930
120	6.9498	7.6260	4.5251	5.5560	3.5641	4.5530
180	6.4525	7.5973	4.4528	5.4134	3.5584	4.4776
240	6.3441	7.7295	4.4085	5.5949	3.5867	4.6083
Model 5						
60	10.5246	12.4055	7.5673	8.6257	6.2568	7.0556
120	9.3436	10.0983	6.9555	7.6742	5.7832	6.3814
180	9.4348	10.0828	6.7791	7.5129	5.6892	6.3846
240	8.8840	10.0905	6.7416	7.5896	5.7096	6.4013

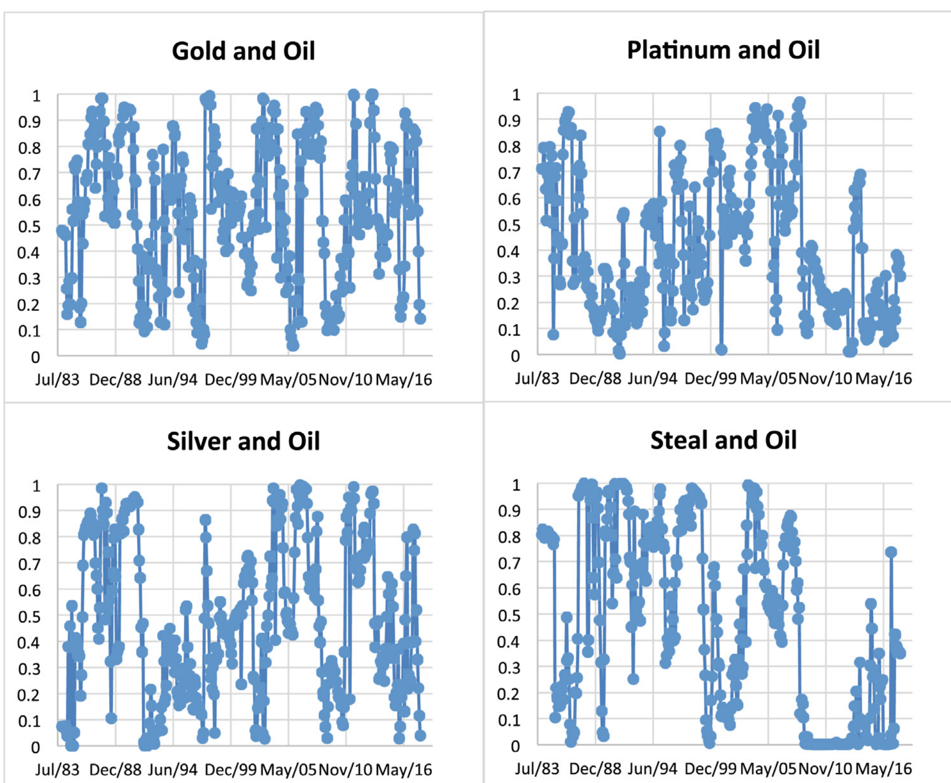

Fig. 1. P-Values for Rolling Window of Size $T_R = 60$.

1979 to May 1999 and from June 1980 to December 200) and one relatively shorter time period (from January 1980 to January 2000). Apart from these three time periods, there are some evidences of long run relationship, but they are not consistent and are not worth mentioning. There are evidence of the existence of cointegration between platinum and oil for two relatively shorter time periods (one from October 1979 to September 2000 with one spike in p-values and the other from October 1988 to January 2009) and one relatively longer time period from August 1989 to June 2015 with one spike in p-values. For the pair of silver and oil, significantly, six different time periods are observed in which the evidence about the existence of cointegration are found. From these six; three

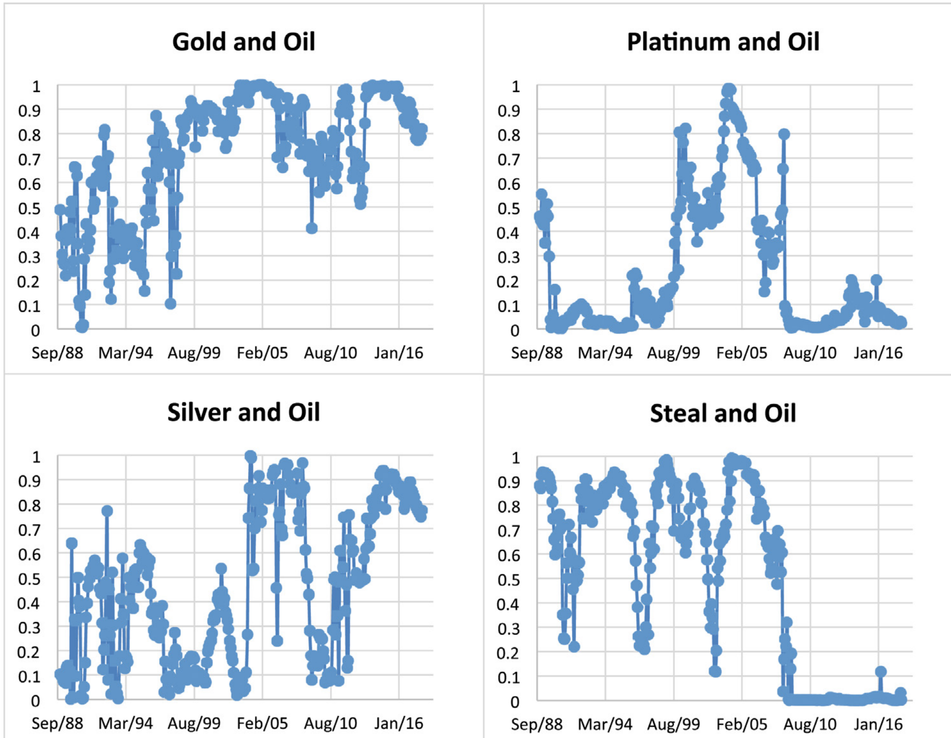

Fig. 2. P-Values for Rolling Window of Size $T_R = 120$.

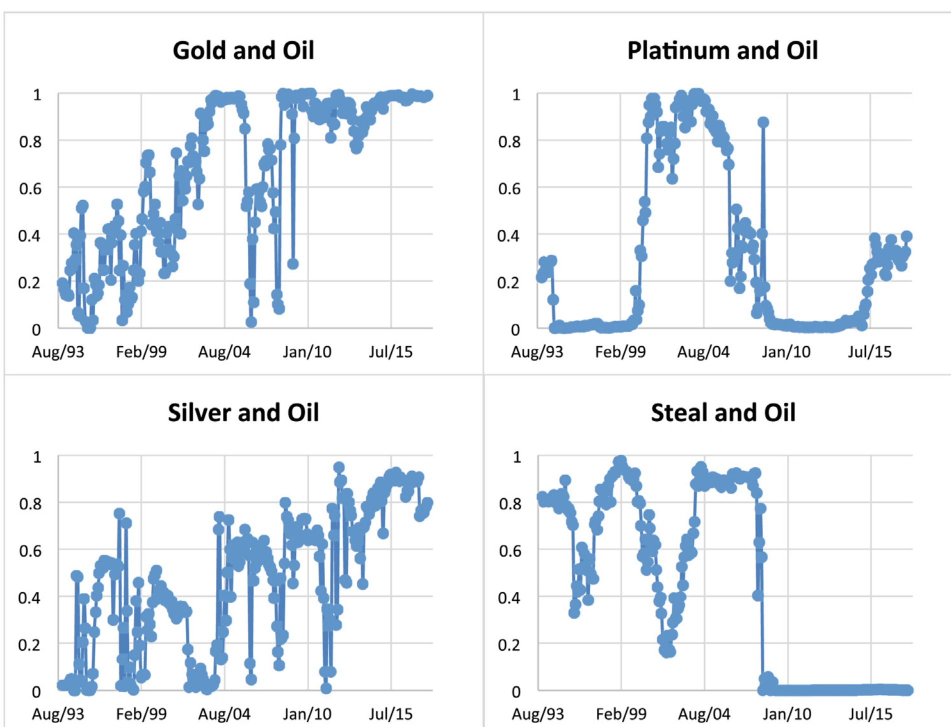

Fig. 3. P-Values for Rolling Window of Size $T_R = 180$.

time periods are relatively longer (from January 1979 to October 1999, from August 1980 to December 2000 and from November 1982 to November 2003 with three spikes in p-values) and three time periods are relatively shorter (from February 1980 to March 2000, March 1988 to April 2008 and from April 1991 to April 2011). The evidence of the existence of cointegration between steel and oil are very strong and compelling for a very long period of time i.e. from July 1988 to December 2017. In this time period, most of the time, cointegration between steel and oil exists at 1% level of significance.

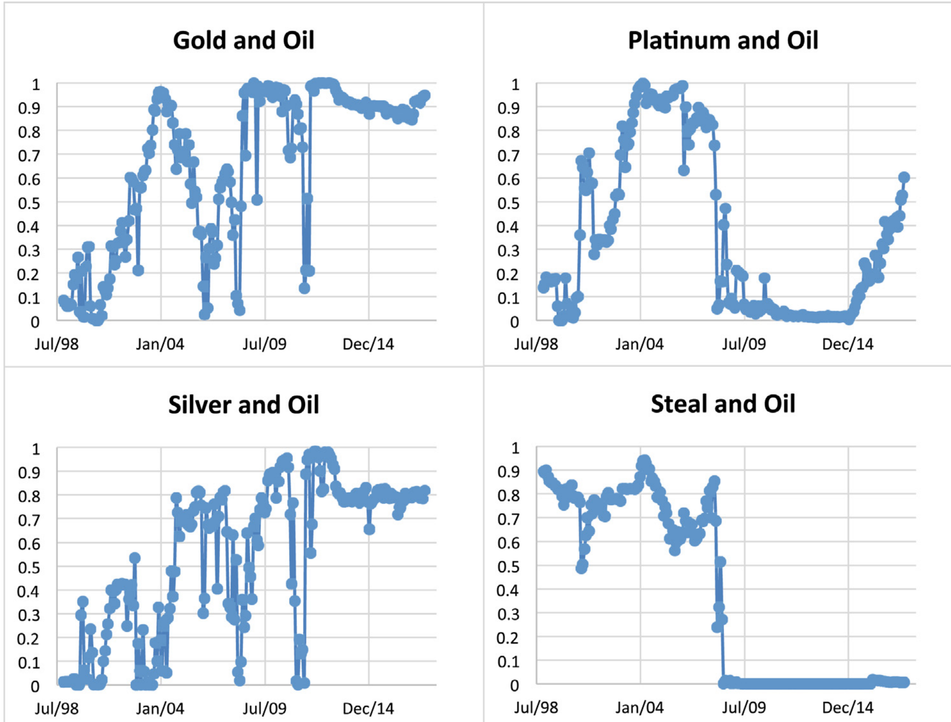

Fig. 4. P-Values of FUB for Rolling Window of Size $T_R = 240$.

5. Conclusion and future research directions

This paper investigated the existence of cointegration between oil prices and metal prices for the period of 1979–2017 using month frequency data. The cointegration between oil prices and metal prices is examined by applying the rolling-window autoregressive lag modeling (RARDL) testing approach by considering four rolling windows of 5, 10, 15, and 20 years. The empirical results confirm the absence of cointegration between oil prices and metals prices i.e. gold, platinum, and silver with a small rolling window of 5 years, but cointegration is valid between oil prices and steel prices from December 2003 to December 2014. In large rolling-windows of 10, 15, and 20 years, cointegration is invalid between oil prices and gold prices, but steel, silver and platinum show cointegration with oil prices in different periods.

The Rolling-Window ARDL (RARDL) testing approach tries to capture whether the long run relationship is constant or time-varying throughout the time span of the considered time series. However, the RARDL has some limitations; the selection of the size of Rolling-Window, not able to use the full information provided and incapable of capturing the time-varying cointegrating vectors. Different sizes of rolling-windows have been considered in this paper to address the first limitation. In the future, a Recursive ARDL testing approach will be considered to address the second limitation of "not using the full information provided". The most important and vital limitation which also covers the first two limitations, is the "incapability of capturing time-varying cointegrating vector". In the future, a Time-varying ARDL (TVARDL) testing approach will be developed to address this limitation by assuming a time-varying cointegrating vector(s).

Data availability

Data will be made available on request.

Disclosure statement / authors' agreement

No conflict of interest exits in the submission of this manuscript, and manuscript is approved by all authors for publication. I would like to declare on behalf of my co-authors that the work described was original research that has not been published previously, and not under consideration for publication elsewhere, in whole or in part. All the authors listed have approved the manuscript that is enclosed.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.qref.2022.01.015.

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