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Co-integration analysis with structural breaks: South Africa's gold mining index and USD/ZAR exchange rate

Abstract

This paper examines the presence of cointegration between South African gold mining index and USD/ZAR exchange rate. The results show that gold index and USD/ZAR exchange rate series are both $I(1)$ and are cointegrated. The Granger causality test shows a two-way directional causality between gold index and USD/ZAR exchange rate for the period 9 June 2005-9 June 2015. By accounting for possible structural breaks, the Zivot-Andrews unit root test suggests two different breaking points in the data. By using the breaking dates to divide the dataset into 3 sub-periods, the results show that gold index and USD/ZAR exchange rate series are not cointegrated. The Granger causality test shows no causality between the two variables. This finding suggests that gold mining index does not play a key role in explaining the trends in the exchange rate and likewise exchange rate does not affect gold mining index.

Keywords: USD/ZAR exchange rate, gold mining index, unit root tests, breaking points, cointegration.
JEL Classification: F3, F4, F63, O47.

Introduction

South Africa's international competitive status is considered key when evaluating its efforts of achieving major macro-economic objectives. Global competitiveness is, nevertheless, a multidimensional concept which is challenging to understand using a single indicator (de Jager, 2012). However, according to Walters and de Beer (1999), the country's real exchange rate is often used to reflect its relative competitive position in international trade. The exchange rate movements affect the country's international relations (Nelson, 2015). Due to this, the importance of studying the variables that affect the exchange rate in an effort to put an economy on the global map cannot be over emphasized. Arezki et al. (2014) noted that increased volatility in the exchange rate cripples the economy through its adverse consequences on private agents' consumption and investment decisions, and challenges commodity export due to exchange rates fluctuations.

The rate of exchange expresses the value of a currency in terms of the home currency (Munro, 2014). This value is determined by the forces of demand and supply for currencies in the foreign exchange market (Nelson, 2015). The relative demand for currencies reflects the causal demand for goods and services denominated in that currency. Depreciation in the currency value causes imported commodities to become relatively expensive, worsening the economy, especially if the country depends heavily on imports (Nortey et al., 2015). International capital flows can also have a strong influence on the demand for various currencies (Ehlers & Takas, 2013).

The foreign exchange authorities can use policies to influence the supply of their currency in international capital markets. The early economic models of exchange rates assumed that the exchange rate is determined by money supply and output levels of the countries (Hopper, 1997). However, Hauner et al. (2011) indicated the difficulty of antedating the likely variable among competing models, especially for short periods (less than one year).

Amid heightened concerns over exchange rate movements, which include its negative impact on growth and employment in many countries, disagreements over exchange rate policies have broadened following the global financial crisis (Nelson, 2015). There has been a belief that some countries practice competitive devaluation in an effort to achieve high exports. This competitive devaluation, sometimes called currency war, has become quite common where countries compete against each other to achieve a comparatively low exchange rate (Saccomanni, 2015). The question is: are countries using policies to intentionally push down the value of their currency in order to gain trade advantages at the expense of other countries? If this be the case, the results could be high production of exports and import-competing goods, which could assist boost export-led growth and job creation in the export sector.

Gold was one of the first metals humans mined (Sujit & Kumar, 2011). Gold as a commodity has maintained a unique function as a means of exchange due to its high liquidity status. Investment in gold can be used as hedge against currency depreciation. Economically, fluctuations in the price of gold are imperative, as they can affect some important economic variables. Logically, one would expect a posi-

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tive correlation between gold price fluctuations and exchange rate movements. According to Bhunia and Pakira (2015), this correlation between exchange rate movements and gold price fluctuations is high and important, since they both play a vital role in persuading the investor's confidence in the economy. They further suggest that the causal effects of exchange rate movements on gold price fluctuations may help investors to use investments in gold as a safe haven against exchange rate movements.

Generally, exchange rates across the world have fluctuated extensively (Nelson, 2015). The South African rand has been trading weaker against the US Dollar (USD) with the recent trend indicating the USD appreciating extensively against the rand (Scotiabank, 2016). According to Ricci (2005), USD/ZAR exchange rate's volatile episodes impact negatively on the performance of the South African economy. The country's total reserves remain some of the world's most variable, and being the sixth largest world producer of gold, is no exception to exposure to volatility in the USD/ZAR exchange rate (Arezki et al., 2014). According to Barr and Kantor (2012), in the short term, a weaker rand is associated with a falling dollar input costs and, hence, for any given dollar gold price, higher dollar profits. It is, then, important to investigate the casual relationship between gold prices and exchange rates in the South African context.

Policies have been developed on exchange rates in an attempt to address major shocks in the form of significant gold price reductions (Aron et al., 1997). The South African economy depends greatly on the mining sector (gold) as an important foreign currency earner (Nattrass, 1995) where gold accounts for more than one-third of South Africa's exports (Bhorat et al., 2014). This depicts the exports' heavy reliance on natural resources in South Africa.

There are studies on the causal relationships between commodity prices and exchange rates (Frankel, 2007; Cashin et al., 2004; Zhang, Dufour & Galbraith, 2013; and Arezki et al., 2014). A study by Bhunia and Pakira (2014) found Granger causality from gold price to US/AUS$ exchange rate in the long period. Ferraro Rogoff and Rossi (2015) studied the relationship between gold price movement and the ZAR/US$ exchange rate and found a short term relationship between the two. A research by Arezki et al. (2012) indicated that the episodes of increases in gold prices have somewhat been followed by episodes of appreciations in the South African rand. A further study by Arezki et al. (2014) found that real exchange rate and gold prices have a long-run relationship. This current study will divert from the previous studies in that it will make use of a breaking point determined by the date of implementation of a policy change. In the present paper, we examine the relationship of gold prices (in USD) and USD/ZAR exchange rate accounting for endogenous structural breaks in the two variables.

The remainder of the paper is organized as follows. Section 1 describes the data and data source. In section 2, the description of the methodology used to analyze the data sets is discussed. Section 3 and final section discuss the main empirical results and conclusions, respectively.

1. Data

To investigate cointegration and causality between gold mining index and exchange rates, we use the daily JSE gold mining index (J50) and daily USD/ZAR exchange rate from 9 June 2005 to 9 June 2015 obtained from INET BFA database. Table 1 shows the variable description and symbols used in this paper.

Table 1. Description of variables and corresponding symbols

Description of variable	Symbol
Gold mining index at time *t*	GMI_t
United States of America Dollar to South African Rand exchange rate at time *t*	USD/ZAR_t

Figure 1 shows the time series plot of GMI_t (in thousands) and USD/ZAR_t From Figure 1, it seems that GMI_t and USD/ZAR_t are trending together in unison which suggests a long-run relationship between the two variables.

2. Methodology

This study focuses on testing the causal relationship between USD/ZAR exchange rate and gold mining index. In this section, we discuss the unit root test and the Johansen-Juselius cointegration test.

2.1. Unit root test: ADF test. The Augmented Dickey-Fuller (ADF) test is commonly used for testing stationarity in time series data. The test is also known as the unit root (non-stationary) test. There are three cases of the ADF test equation depending on the nature of the time series data.

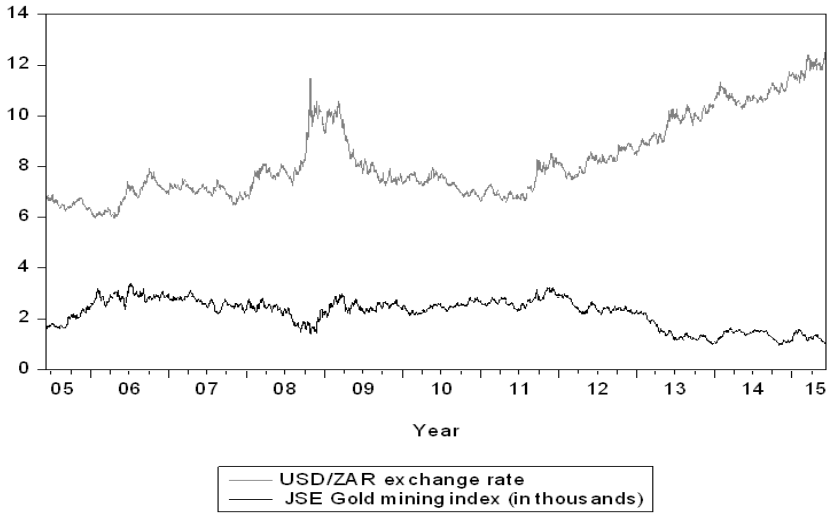


Fig. 1. Time series plot of daily gold mining index and USD/ZAR exchange rate

When the time series is flat (no trend) and potentially slow-turning to zero, the test equation is:

$$\Delta\rho_t = \alpha\rho_{t-1} + \psi_1\Delta\rho_{t-1} + \psi_2\Delta\rho_{t-2} + \ldots + \psi_p\Delta\rho_{t-p} + \varepsilon, \quad (1)$$

The equation has no intercept and no time trend.

When the time series is flat (no trend) and potentially slow-turning to non-zero value, the test equation is:

$$\Delta\rho_t = \mu + \alpha\rho_{t-1} + \psi_1\Delta\rho_{t-1} + \psi_2\Delta\rho_{t-2} + \ldots + \psi_p\Delta\rho_{t-p} + \varepsilon, \quad (2)$$

The equation has an intercept term (μ), but no time trend.

When the time series has a trend (either up or down) and is potentially slow-turning around a trend, the test equation is:

$$\Delta\rho_t = \mu + \alpha\rho_{t-1} + \gamma t + \psi_1\Delta\rho_{t-1} + \psi_2\Delta\rho_{t-2} + \ldots + \psi_p\Delta\rho_{t-p} + \varepsilon, \quad (3)$$

where μ is the intercept term, γt is the time trend and μ, γ and ψ_i's are the parameters to be estimated. In all cases, ε_t is a white noise error term (Eviews 8 Manual). The lag length (p) is selected by using the Schwarz's Bayesian Criterion (SBC).

The null and alternate hypotheses for the equations are:

$$H_0: \alpha = 0,$$

$$H_1: \alpha < 0.$$

Accepting the null hypothesis indicates the presence of a unit root. The alternative hypothesis in case of equation (2) implies a mean-stationary process and that in equation (3) is for a trend-stationary process. Therefore, we are able to identify whether the time series under investigation are mean-stationary, trend-stationary or non-stationary. According to Chomobi (2010) cited in Niyimbanira (2013), the ADF test relies on rejecting the null hypothesis if the data need to be differenced to achieve stationarity in favor of the alternative hypothesis that the dataset is stationary and does not need differencing.

2.2. Unit root test in the presence of structural breaks. Cointegration usually starts with the testing of a unit root in the series under investigation. The Augmented Dickey-Fuller (1979) test (ADF) is the most commonly used unit root test in applied statistics. However, it does not account for structural breaks which are common in long-span time series (Chen and Saghaian, 2015; John et al., 2007). The ADF test is biased towards non-rejection of the null hypothesis if there is a structural break in a stationary time series (Perron, 1989). There are several tests available to test for unit root in the presence of structural breaks. Banerjee et al. (1992), Perron and Vogelsag (1992), Perron (1997), Lumsdaine and Papell (1998) and Zivot-Andrews (1992) are some of the unit root tests which account for structural breaks in the span of the time series. Zivot-Andrews (1992) unit root test is a modification of the Perron unit root test. The Perron (1989) test allows for a one-time structural break occurring at time T_B where $1 < T_B < T$, and T is the number of observations. The breaking point is exogenously determined. The main difference between the Perron (1989) test and Zivot-Andrews (1992) test is the determination of the breaking point. The breaking point is endogenously determined in the Zivot and Andrews test. In this paper, we employ the Zivot and Andrews (1992) test, since we expect the existence of structural breaks in the USD/ZAR exchange rate and gold mining index.

Zivot-Andrews (1992) endogenous structural break test is a sequential test which utilizes the full sample and uses a different dummy variable for each possible break date (John et al., 2007). The selection of the time of the break is treated as the outcome of an

estimation procedure and is not predetermined. A break date is selected where the t-statistic from the ADF test is at a minimum. The optimum break date is chosen where the evidence is least favorable for the unit root null (Saatcioglu and Korap, 2008). The three cases of the Zivot-Andrews test are:

$$\Delta\rho_t = \hat{\mu} + \hat{\theta}DU_t(\hat{\lambda}) + \hat{\gamma}t + \hat{\alpha}\rho_{t-1} + \hat{\psi}_1\Delta\rho_{t-1} + ... + \hat{\psi}_p\Delta\rho_{t-p} + \hat{\varepsilon}_t, \quad (4)$$

$$\Delta\rho_t = \hat{\mu} + \hat{\gamma}t + \hat{\beta}DT_t^*(\hat{\lambda}) + \hat{\alpha}\rho_{t-1} + \hat{\psi}_1\Delta\rho_{t-1} + ... + \hat{\psi}_p\Delta\rho_{t-p} + \hat{\varepsilon}_t, \quad (5)$$

$$\Delta\rho_t = \hat{\mu} + \hat{\theta}DU_t(\hat{\lambda}) + \hat{\gamma}t + \hat{\beta}DT_t^*(\hat{\lambda}) + \hat{\alpha}\rho_{t-1} + \\ + \hat{\psi}_1\Delta\rho_{t-1} + ... + \hat{\psi}_p\Delta\rho_{t-p} + \hat{\varepsilon}_t, \quad (6)$$

where $\hat{\mu}, \hat{\theta}, \hat{\gamma}, \hat{\beta}, \hat{\alpha}$ and $\hat{\psi}_i$'s are parameters to be estimated. $DT_t^* = t - T_B$ if $t > T_B$ and 0, otherwise. $DU_t = 1$ if $t > T_B$ and 0, otherwise. $\hat{\lambda} = T_B/T$ is the location of the breaking point. The breaking location is endogenously estimated in these equations (Narayan and Smyth, 2004). The t-statistic for α is calculated over different values of T_B (possible breaking points) and the break point (date) is selected as the point corresponding to the minimum ADF t-statistic α (Zivot & Andrews, 1992). The lag length (p) is selected by using the Schwarz's Bayesian Criterion (SBC).

2.3. Testing for cointegration. To investigate the possible existence of a long-run equilibrium relationship between gold mining index and USD/ZAR exchange rate, we use the Johansen-Juselius Full Information Maximum Likelihood (ML) technique (Johansen, 1988; Johansen & Juselius, 1990). According to Kadir & Jusoff (2010), Lean (2008) and Hallam & Zanoli (1993), the Johansen-Juselius approach provides a more accurate estimate for the parameters of the long-run relationship. The basic idea behind cointegration is that nonstationary variables may share a common stochastic trend which can be eliminated by taking a linear combination of the variables. Just like the unit root test, there can be a constant term, trend term, both or neither in the model. If there is co-integration between two variables, there exists a long-run effect that prevents the two series from drifting away from each other. This will force the two series to converge into a long-run equilibrium. The Johansen's methodology takes its starting point in the vector autoregression (VAR) model of order p given by

$$y_t = \mu + A_1 y_{t-1} + ... + A_p y_{t-p} + \varepsilon_t, \quad (7)$$

where y_t is an $n \times 1$ vector of variables that are I (1) and ε_t is an $n \times 1$ vector of innovations. The VAR model can be rewritten as:

$$y_t = \mu + \Pi y_{t-1} + \sum_{i=1}^{p-1} \Gamma_i \Delta y_{t-i} + \varepsilon_t, \quad (8)$$

where

$$y_t = \mu + A_1 y_{t-1} + ... + A_p y_{t-p} + \varepsilon_t,$$

$$\Pi = \sum_{i=1}^{p} A_i - I \text{ and } \Gamma_i = -\sum_{j=i+1}^{p} A_j. \quad (9)$$

Let r be the number of cointegrating relationships. If the coefficient matrix Π is of reduced rank, i.e., $r < n$, then, there exists $n \times r$ matrices, α and β each with rank r such that $\Pi = \alpha\beta'$ and $\beta' y_t$ is stationary. The elements of α are called adjustments parameters in the vector error correlation model (VECM). Each column of β is a cointegrating vector. The maximum likelihood estimator of β defines the combination of y_{t-1} that yields the r largest canonical correlations of Δy_t and y_{t-i} after correcting for lagged differences and deterministic variables, if present. Johansen and Juselius (1990) proposed two different likelihood ratio tests, namely, the trace test and maximum eigenvalue test. The trace test is given by:

$$J_{Trace} = -T\sum_{i=r+1}^{n} \ln(1 - \hat{\tau}_{r+1}), \quad (10)$$

and the maximum eigenvalue test is given by

$$J_{Max} = -T\sum_{i=r+1}^{n} \ln(1 - \hat{\tau}_{r+1}), \quad (11)$$

where T is the sample size and $\hat{\tau}_i$ is the ith largest canonical correlation. The null hypothesis of the trace test is that there are r cointegrating vectors which are tested against the alternate hypothesis of n cointegrating vectors. The maximum eigenvalue approach tests the null hypothesis of r cointegrating vectors against the alternative hypothesis of $r + 1$ cointegrating vectors (Johansen, 1995; Johansen and Juselius, 1990). The critical values of the tests are provided in the paper by Johansen and Juselius (1990).

2.4. Granger causality tests. The test of cointegration is designed to examine the long-run or equilibrium relationship and rule out spurious relationship between GMI_t and USD/ZAR_t, but the evidence of cointegration cannot tell us which variable is leading and which variable is lagging. This can be done by the test of the VECM that can indicate the direction of Granger causality both in the short and long run (Mashi et al., 2010).

2.4.1. Test of Granger causality using VECM. We further explore the relationship between the series using the Granger causality approach. If the series are found to be cointegrated, then, there must be Granger causation in at least one direction (Granger, 1998). In the Granger causality sense, X having a causality effect on Y means X is a cause of Y, if it is useful in forecasting . Y_1 Hansen and Rand (2005) emphasized the importance of including the Error Correction Term (ECT) in the model if the two variables are cointegrated. The bivariate autoregression of the relationship between gold mining index (GMI) and USD/ZAR exchange rate (USD/ZAR) is:

$$\Delta GMI_t = \alpha_0 + \sum_{i=1}^{n} \alpha_{1,t} \Delta GMI_{t\text{-}1} + \sum_{i=1}^{m} \alpha_{2,t} \Delta USD/ZAR_{t\text{-}1} + \delta_1 ECT_{t-1} + \varepsilon_{1,t}, \quad (12)$$

$$\Delta USD/ZAR_t = \beta_0 + \sum_{i=1}^{n} \beta_{1,t} \Delta USD/ZAR_{t\text{-}1} + \sum_{i=1}^{m} \beta_{2,t} \Delta GMI_{t\text{-}1} + \delta_2 ECT_{t-1} + \varepsilon_{1,t}, \quad (13)$$

where α_0 and β_0 denotes the deterministic component and $\varepsilon_{i,t}$ is white noise. $ECT_{t\text{-}1}$ is the error correction term. The estimates of δ_1 and δ_2 can be interpreted as the speed of adjustments. As in equation (11), $USD/ZAR_{t\text{-}1}$ is said to "Granger-cause", GMI_t if the error correction term $ECT_{t\text{-}1}$ is different from zero even though the sum of the coefficients of lagged $USD/ZAR_{t\text{-}1}$ is insignificant. If cointegration between the two variables under study does not exist, the standard Granger causality approach can be employed without including the error correction term ($ECT_{t\text{-}1}$) (Granger, 1969).

2.4.2. ARIMA models and cross-correlations approach. We can also check for Granger causality between GMI_t and USD/ZAR_t sing the Autoregressive integrated moving average (ARIMA) model approach. If the GMI_t and USD/ZAR_t series are stationary, Autoregressive moving average processes of order p and q, i.e., ARMA (p, q):

$$(1 - \sum_{k=1}^{p} \phi_k L^k) = GMI_t = (1 - \sum_{k=1}^{q} \varphi_k L^k)\mu_t, \quad (14)$$

$$(1 - \sum_{k=1}^{p} \phi^*_k L^{*k}) = USD/ZAR_t = \\ = (1 + \sum_{k=1}^{q} \varphi^*_k L^{*k})\mu^*_t, \quad (15)$$

where ϕ_k, φ_k, ϕ_k^* and φ_k^* are parameters, $L^k$and L^{*k} are time lag operators while μ_t and μ_t^* are innovations of equations (14) and (15), respectively, then, we can consider the cross-correlation functions of the two series. Under the null hypothesis of independence (no Granger causality in either direction), the cross-correlation of the innovations μ_t and μ_t^* will be zero at all positive and negative lags. The approach does not inform on the directionality of causality, but the presence or absence of it, thus, we use this approach in this paper to confirm absence of causality between GMI_t and USD/ZAR_t. In order to perform this test, we estimate an appropriate ARIMA model for each series, extract their respective innovations μ_t and μ_t^* and estimate the cross-correlations of the extracted innovations. If there is no Granger causality between the two series, the cross-correlation values all lie within ±2 standard errors from zero (Mok, 1993).

2.5. Variance decomposition. The VECM does not tell us which variable is relatively more exogenous or endogenous. The variance decomposition technique indicates the relative exogeneity or endogeneity of a variable. The technique decomposes (partitions) the variance of the forecast error of a variable into proportions attributable to innovations in each variable in the system including its own. The proportion of the variance explained by its own past innovations can determine the relative exogeneity or endogeneity of a variable. The variable that is explained mostly by its own innovations is deemed to be the most exogenous of all. We use impulse response function, a graphical method which exposes the relative exogeneity or endogeneity of a variable. The impulse responses trace out the response of current and future values of each of the variables to a one-unit increase in the current value of one of the VAR innovations, assuming that this innovation returns to zero in subsequent periods and that all other innovations are equal to zero.

3. Empirical results

In this section, we systematically investigate the relationship between GMI_t and $USD/ZAR_{t\text{-}1}$. The descriptive statistics of the two data series are shown in Table 2. The minimum gold mining index was recorded on 31 October 2014 and the maximum index on 12 July 2006. Generally, there has been a notable negative trend of the indices of gold and other precious metals between 2006 and 2015. The lowest *USD/ZAR* exchange rate was recorded on 23 January 2006, while the highest exchange rate was recorded on 8 June 2015. The USD/ZAR_t series has a positive trend between 2006 and 2009, then, a negative trend between 2009 and 2011. The last span under investigation (2011-2015) the USD/ZAR_t series has a positive trend.

Table 2. Descriptive statistics

	No. of obs	Mean	Std. dev.	Min	Max	Skewness	Excess kurtosis
GMI_t	2500	2235.445	577.666	957.720	3404.720	-0.599	-0.796
USD/ZAR_t	2500	8.267	1.581	5.968	12.574	0.823	-0.454

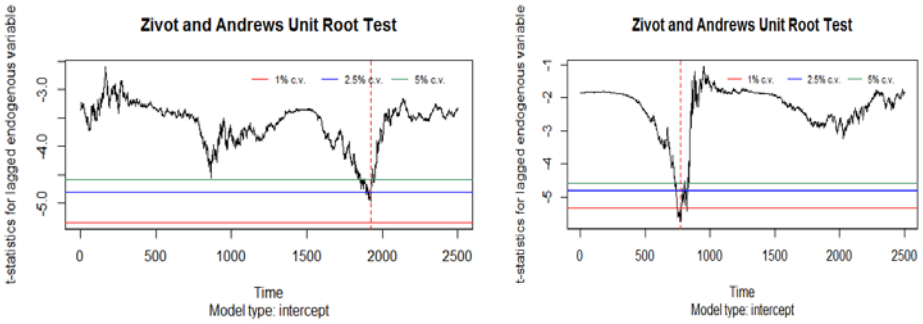
Cointegration analysis usually starts with testing for unit root of the time series under investigation. Table 3 shows the ADF and Phillips-Perron unit root tests of GMI_t and USD/ZAR_t at level and first difference. The futhors find that the series of gold mining index and *USD/ZAR* exchange rate have a unit root problem at the level. The variables are found to be stationary at first difference. This indicates that the variables are integrated at order 1, I (1).

Table 3. Unit root test results: full sample

Variable	w/o trend and intercept				Integration order
	Level		First difference		
	ADF	PP	ADF	PP	
GMI_t	-3.357	-3.281	-36.580***	-47.848***	*I* (1)
USD/ZAR_t	-1.923	-1.704	-51.906***	-52.226***	*I* (1)

Source: test critical values: 1%, 5% and 10% levels are -3.962, -3.412 and -3.128, respectively. ***Significance at the 1% level.

The problem with the ADF and PP unit root tests is that they provide biased empirical evidence if the series contains a structural break. An initial visual examination of Figure 1 suggests that there may be a shift in the linkages between GMI_t and USD/ZAR_t. This could give a first indication of a structural break in the two time series under investigation. To overcome this issue, we apply a unit root test which accounts for structural break in the series under investigation. The authors employed the Zivot-Andrews' unit root test which accounts for structural break in the time series. Figure 2 shows the results of the Zivot-Andrews' unit root test. The GMI_t time series plot has a structural break on 13 February 2013 (Figure 2, Panel A), while there is a structural break on 6 March 2009 for the USD/ZAR_t time series plot (Figure 2, Panel B).



Panel A: Gold mining index's break point **Panel B**: USD/ZAR exchange rate's break point

Fig. 2. Possible breaking points for the two time series using Zivot-Andrews unit root test

Structural breaks can reflect institutional, legislative or technical change. Structural breaks may also be due to changes in economic policies or large economic shocks. This means that the structural break can have a permanent effect on the pattern of the time series. The Zivot-Andrews' unit root tests results are reported in Table 4. All the coefficients of the mean shift variable are significant, substantiating the claim of mean shift.

Table 4. Zivot and Andrews unit root test results: full sample

	Level		First difference	
	GMI_t	USD/ZAR_t	GMI_t	USD/ZAR_t
$\hat{\mu}$	41.89855***	0.00615***	9.31419**	-0.00126
$\hat{\beta}$	0.98394***	0.9892***	0.04267***	-0.04360**
$\hat{\gamma}$	-0.00148	0.00005***	-0.00017	-0.00002***
$\hat{\theta}$	18.83474***	-0.04520***	-9.96754**	-0.02617***
Test statistic	-4.9606	-4.5803	-47.8397	-52.1745
Break date ($\hat{\lambda}$)	13 Feb 2013	1 Feb 2006	6 Mar 2009	23 Oct 2008

Note: The null hypothesis is the series is non-stationary with a single mean shift. $\hat{\theta}$ represents the coefficient of mean shift variable and its corresponding optimal break point is shown in the last row. ***indicates p-values less than 0.001, **indicates *p*-values less than 0.05. The 1% and 5% critical value for this sample is -5.34 and -4.8, respectively.

The two series under investigation have different, but similar breaking points. We use 6 March 2009 and 13 February 2013 as the breaking dates for both series. Since the two series have different, but similar breaking dates, we use both breaking dates. Thus, in our subsequent analysis, we use three sub-periods, namely: sub-period 1 (9 June 2005-5 March 2009), sub-period 2 (6 March 2009-12 February 2013) and sub-period 3 (13 February 2013-9 June 2015). Furthermore, we test for unit root of the time series under investigation of the full sample and the sub-periods. The unit root tests results for the sub-periods are shown in Table 5 (see below).

Table 5. Unit root test results: sub-periods 1-3

w/o trend and intercept						
Sub-period	Variable	Level		First difference		Integration order
		ADF	PP	ADF	PP	
1	GMI_t	-2.779	-2.860	-28.590***	-28.520***	*I* (1)
	USD/ZAR_t	-1.936	-1.771	-31.294***	-31.475***	*I* (1)
2	GMI_t	-3.305**	-3.335**	-24.128***	-31.187***	*I* (1)
	USD/ZAR_t	-4.308***	-4.408***	-31.295***	-31.456***	*I* (0)
3	GMI_t	-3.597***	-3.678***	-22.346***	-22.408***	*I* (0)
	USD/ZAR_t	-3.738***	-3.534***	-27.224***	-27.507***	*I* (0)

The unit root tests reported in Table 3 and Table 5 show that GMI_t and USD/ZAR_t follow the *I* (1) in the full sample and sub-period 1. We, then, proceed with testing for cointegration using the Johansen-Juselius Full Information Maximum Likelihood (ML) technique. Table 6 and Table 8 illustrate the Johansen-Juselius cointegration test results for the full data sample and sub-period 1, respectively.

Table 6. Johansen-Juselius unrestricted cointegration rank test (trace): full sample

Trend: Linear		Number of obs = 2495
		Lags = 4
Null hypothesis	J_{Trace}	J_{Max}
$r = 0$	27.537***	21.162***
$r = 1$	6.375	6.375

Note: ***Significance at 5% level. Full sample: Trace and maximum eigenvalue tests indicate 1 cointegration equation at the 5% level.

Based on the results in Table 6, the trace and maximum eigenvalue tests reject the null hypothesis of no cointegration between the variables at 5% level of significance without accounting for structural break in the time series. Since the variables are cointegrated, we consider the long-run relationship. The long-run effect is given by the coefficient of the error correction term. The long-run coefficients defining the cointegrating relationship are reported in Table 7.

Table 7. Vector error correction model results

Variable	Dependent variable: GMI_t	Dependent variable: USD/ZAR_t
EC_{t-1}	-0.0086 (0.0028)	$-1.56\times 10^{-5}(5.1\times 10^{-6})$
D_GMI_{t-1}	0.0513 (0.0200)	$-8.09\times 10^{-6}(3.06\times 10^{-5})$
D_GMI_{t-2}	-0.0536 (0.0200)	$5.05\times 10^{-5}(3.7\times 10^{-5})$
D_USD/ZAR_{t-1}	-0.8718 (10.9197)	-0.03667 (0.0200)
D_USD/ZAR_{t-2}	-12.7512 (10.9197)	0.0166 (0.0200)
constant	-0.2280 (1.0349)	0.0024 (0.0019)

Note: The table includes the value with the standard error in parentice. EC_{t-1} is the error correction term. All estimates are not siginificantly different from zero.

From the VECM results in Table 7, the one-lagged error correction term is negatively signed and not statistically significant at 5% significance level. This confirms that a long-run relationship between GMI_t and USD/ZAR_t does not exist. However, we are interested in the cointegration of the variables accounting for structural breaks. GMI_t and USD/ZAR_t are *I* (1) only in the sub-period 1. Therefore, we test for cointegration of the variables. The results of Johansen and Juselius cointegration test are reported in Table 8.

Table 8. Johansen-Juselius unrestricted cointegration rank test (trace): sub-period 1

Trend: Linear		Number of obs = 933
		Lags = 4
Null hypothesis	J_{Trace}	J_{Max}
$r = 0$	16.360	10.170
$r = 1$	6.190	6.190

Note: ***Significance at 5% level. Sub-period 1: Trace and Maximum eigenvalue tests indicate no cointegration equation at the 5% level.

Based on the results in Table 8, the trace and maximum eigenvalue tests fail to reject the null hypothesis of no cointegration between the variables at 5% level of significance. This finding suggests no possible long-term relationship between GMI_t and USD/ZAR_t. Since GMI_t and USD/ZAR_t are not both *I* (1) in sub-period 2 and 3, and not cointegrated in sub-period 1, we can conclude that the variables are not cointegrated for the entire period under investigation if we account for structural breaks.

In order to examine the casual relatioship between GMI_t and USD/ZAR_t, as well as the directions of causality, we run the Granger causality test. The estimated VAR for Granger causality analyses are reported in Table 9.

Table 9. Analysis of causal links between GMI_t and USD/ZAR_t: Granger-causality test

Sample	Null hypothesis	Obs	F-statistic	Prob
Full sample	$GMI_t \nrightarrow USD/ZAR_t$ $USD/ZAR_t \nrightarrow GMI_t$	2495	3.981 2.227	0.0013 0.0491
Sub-period 1	$GMI_t \nrightarrow USD/ZAR_t$ $USD/ZAR_t \nrightarrow GMI_t$	933	1.530 0.906	0.178 0.476

Note: The notation "$x \nrightarrow y$" is equivalent to "x" does not Granger cause "y".

By ignoring the structural breaks in the time series under investigation, the Granger causality test for the full sample shows causality relationship in both directions between GMI_t and USD/ZAR_t at 5% level of significance. However, by taking structural breaks into account, the Granger causality test rejects the null hypothesis of Granger causality between the two variables under investigation.

We also test for no Granger causality between GMI_t and USD/ZAR_t in sub-period 1 using the ARIMA models and cross-correlations approach. Results show that ARIMA (0,1,1) and ARIMA (0,1,0) models are the best models for GMI_t and USD/ZAR_t, respectively. The cross-correlation function of the extracted the residuals (innovations) from the ARIMA models are shown in Figure 2. The cross-correlations of the innovations are within the ± 2 standard errors from zero, confirming no Granger causality between the two variables in sub-period 1.

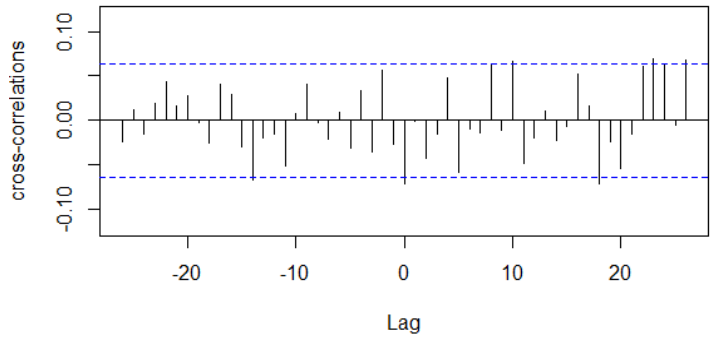


Fig. 2. Auto-correlation function of innovations from ARIMA models

The authors also analyze the impulse response in the full sample. Impulse response analysis traces out the responsiveness of the dependent variable in the VAR model to shocks to the independent variable. It shows the sign, magnitude and persistence of USD/ZAR exchange rate shocks to gold mining index and vice versa. Figure 3 shows the impulse responses.

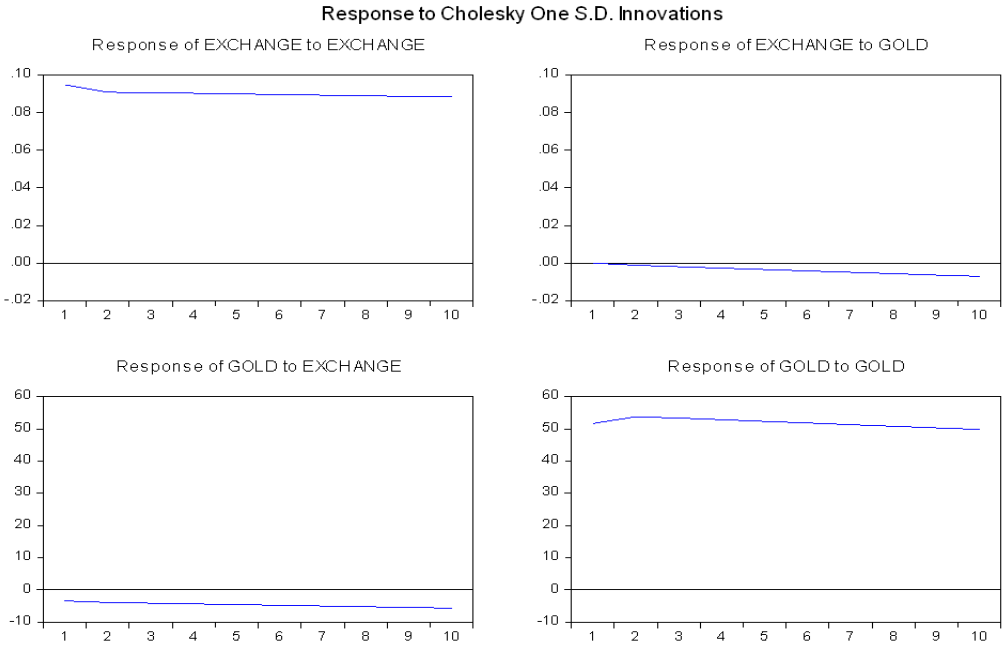


Fig. 3. Impulse responses

Response of: USD/ZAR exchange rate to USD/ZAR exchange rate. There is a positive relationship between USD/ZAR exchange rate and response to its self in the ten years into the future. However, a unit standard deviation positive shock of USD/ZAR exchange rate will cause itself to decrease slightly two years in to the future.

USD/ZAR exchange rate to gold mining index. A slight standard deviation positive shock of gold mining index will cause USD/ZAR exchange rate to decrease below the optimal point (0). This shows a negative relationship between USD/ZAR exchange rate and gold mining index.

Gold mining index to USD/ZAR exchange rate. A slight standard deviation positive shock of USD/ZAR exchange rate will cause gold mining index to decrease below the optimal point (0) at least four years into the future. However, gold mining index is kept almost negative constant variation into the next six years. This shows a negative relationship between gold mining index and USD/ZAR exchange rate.

Gold mining index to gold mining index. There is a positive relationship between gold mining index and response to its self in the ten years into the future. However, a unit standard deviation positive shock of gold mining index will cause itself to increase slightly two years in to the future.

Conclusions

The focus of this paper was to assess the existing evidence of causal interdependence between daily gold mining index and USD/ZAR exchange rate when accounting for structural breaks. Our preliminary results indicate interdependence between the two variables. This result confirms the results by previous studies (Arezki et al., 2014; Bhunia & Pakira, 2014; Rogoff and Rossi, 2015) However, the VECM indicates that the long-run relationship between GMI_t and USD/ZAR_t does not exist at 5% level of significance. After accounting for structural breaks in the time series, this study found that GMI_t and USD/ZAR_t does not cointegrate and there is no evidence of Granger causality between the two variables. It is the argument of this paper that when we account for endogenous structural breaks in the datasets, there is no evidence of cointegration between the variables. This finding is new and important, especially to the South African government and investors in the gold mining industry. The absence of dependence of gold mining index on the USD/ZAR exchange rate may be cheered by policy makers and mining companies, especially during this era of high volatility in USD/ZAR exchange rate.

Implications

The study, after considering structural breaks in the data, found no cointergration between gold mining index and the USD/ZAR. These results have important macro-economic policy implications for both domestic policy-makers and the country's trading partners. Gold mining index movements may affect the exchange rate if structural changes are not accounted for. In this regard, with the prevalence of unforeseen structural changes, long-run forecast could be better estimated based on results that account for such. To policy-makers, this could imply that there are other factors which could influence the USD/ZAR exchange rate which may require investigation such as foreign investments, technological progress, human capital development and resource endowment of the country. From a forecasting perspective, an assumption should be made if the single-break model is considered as a simile for multiple irregular breaks. A break may be a one-time event or at times occur frequently. However, care should be taken since these predictors might have the same forecast biases for breaks that occur after forecasts are announced (Clements & Hendry, 1999).

We suggest the following channels for future research. Firstly, the study used South African data, future studies should focus on other countries and compare the results. Secondly, since there was no cointergration between the USD/ZAR exchange rate and the gold mining index after accounting for structural breaks, the study suggests that future studies should concentrate on investigating foreign direct investment, oil prices, imports and other variables to see if they affect the USD/ZAR exchange rate when accounting for structural breaks in the data set. Lastly, this present study suggests an expansion of the data set. This will make it possible to detect cointergration between USD/ZAR exchange rate and the gold mining index. A longer data set will produce ideal results for long run decision making.

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