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Precious metal abundance and economic growth: Evidence from top precious metal producer countries

Melike E. Bildirici [a,*], Seyit M. Gokmenoglu [b]

[a] *Yıldız Technical University, Department of Economics, Davutpasa, Istanbul, 34220, Turkey*
[b] *Yıldız Technical University, Institute of Social Sciences, Davutpasa, Istanbul, 34220, Turkey*

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ABSTRACT

In this study, metal curse hypothesis was suggested for top precious metal producer countries, i.e. Australia, Canada, Mexico, Philippines, Peru, South Africa and the USA by using nonlinear Smooth Transition Autoregressive Distributed Lag (STARDL) models for the period 1963–2017. We used precious metal production data as an indicator for resource richness. According to the analysis results of STARDL models, we found statistically significant regime specific long-run and short-run relationships between economic growth and each precious metal type under analysis. We couldn't find supporting results for metal curse for Canada, Philippines, Peru, South Africa and the USA, but the positive effect of each precious metal abundance is asymmetric between the regimes. For Australia and Mexico, the effect of precious metal abundance on economic growth is various depending on precious metal type, the regime which the economy is in, the short- and long-run.

1. Introduction

Most people have a dream about winning the big prize in a national lottery to live in prosperity and richness. However, the large windfall gain doesn't generally increase prosperity in the long-run, it may even cause the winner to be in a worse situation than before the win. Likewise, the discovery of large amounts of metal resource reserves in a low- or middle-income country can be a significant opportunity to increase the welfare of it. It is among the issues discussed in the economic growth literature why some countries cannot turn this unique opportunity into a success although others can. The phenomenon that natural resource-richness has a negative effect on economic growth is called the resource curse in the literature. The term was first used by Gelb (1988) in his study that found a negative effect of oil revenues on economic growth. The concept of the metal curse is similar to the resource curse in the literature, implying the negative effect of metal-richness on economic growth. In this paper, we investigate if large amounts of precious metal reserves can be a significant opportunity to increase welfare. Most metal-rich countries in the Middle East, North Africa and South America perform low economic performance. On the other hand, it is possible to come across countries such as Canada, and the USA, which increase economic growth even though they are rich in metal resources. What makes the difference? Is the metal curse hypothesis valid for every metal-rich country and every metal type? How to avoid the metal curse? The literature for the metal curse is very scarce. Auty (1993) found that the pace of economic growth in Chile, Peru, Zambia, Papua New Guinea, Bolivia, and Jamaica were slower than the average growth rate of other developing economies which were not blessed with hard mineral (copper, tin and bauxite) endowment, just as in oil-exporting countries. Bildirici and Gokmenoglu (2019) found that the effect of precious metal production on economic growth are various by utilizing MS-VEC models. In this study, we aimed to contribute to the literature by focusing only on one natural resource type, precious metals and investigated whether metal curse hypothesis is valid for the biggest producer countries of precious metals (Australia, Canada, Mexico, Peru, Philippines, South Africa and the USA). We did not deal with transmission channels while analyzing the relationship because our focus was on the direct impact of precious metal productions on economic growth. Most of the studies on resource curse hypothesis use exportation data as an indicator of natural resource richness and linear cross-sectional or time series analysis methods to investigate the relationship. Yet the precious metals are not only used for exportation but also for industrial consumption. Hence, we adopted mine production data as a measure of natural resource richness. Most of the financial and economic data such as economic growth, inflation rates, interest rates and unemployment rates have a nonlinear characteristic. It is very important to take into

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* Corresponding author.
E-mail addresses: melikebildirici@gmail.com (M.E. Bildirici), smgokmen@gmail.com (S.M. Gokmenoglu).

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consideration the nonlinear structure of the series to get realistic results. However, the cross-sectional analysis method suffers from some problems such as endogeneity bias. It also cannot identify the dynamics and test the short- and long-run effects. Hence, we utilized one of the nonlinear time series analysis methods, Smooth Transition Autoregressive Distributed Lag (STARDL) models, to investigate the metal curse hypothesis in precious metal producer countries.

The article proceeds as follows. The second section covers the transmission mechanism between natural resource richness and poor economic growth. The third section presents the reasons for the diversity in the empirical literature on the resource curse hypothesis. Data and econometric methods are presented in the fourth section. The fifth section includes the results of the analysis. Finally, the last section presents conclusions and policy implications.

2. Transmission channels between natural resource abundance and poor economic growth

There are widely accepted four transmission channels for explaining the adverse effect of natural resource richness on economic growth in literature: Dutch disease, price volatility, rentier-state and the crowding-out effect. The most known channel is Dutch disease which was coined by an article published in The Economist in 1977 to describe the recession in the manufacturing sector of the Netherlands following the discovery of the gas reserves. It puts forward that the exportation of the huge amount of extracted natural resources draws a substantial amount of foreign currency into the country, inducing an appreciation of the local currency. This appreciation has a negative effect on the competitiveness of the manufacturing sector and thereby leads to shifting capital and labor force from the manufacturing sector to the resource and the service sectors (Corden, 1984). This effect also deteriorates terms of trade and excludes manufacturing sector which is a key driving force of sustainable economic growth. Undoubtedly, losing competitiveness and drawing labor force away from manufacturing and agricultural sectors can destroy positive externalities, learning-by-doing and forward and backward linkages between manufacturing sectors, which, in turn, has an adverse effect on economic growth (Elbra, 2017).

The price volatility view claims that fluctuations in the price of commodity goods (e.g., oil, gas and minerals) in world markets can lead to revenue fluctuation. Moreover, a sharp decline in the prices may result in economic shocks, if the country mainly relies on the revenues got from the exportation of these goods. According to Ross (2003), international prices of commodity goods were more volatile than those of manufactured goods in the last century. The demand volume of most precious metals and minerals fluctuates according to business operations and personal income (Crowson, 2009, p. 21). These fluctuations in revenues trigger exchange rate volatility, which creates uncertainty that could be seriously detrimental to foreign investments, exports of tradeable goods and economic growth (Gylfason, 2004; Budina et al., 2007).

The third channel, rentier-state, is related to political economics. The argument about the resource curse mainly revolves around this channel and institutional quality. Undoubtedly, one of the important drivers of economic development is a strong institutional infrastructure in the country. The poor institutional quality makes it harder to implement micro and macro-economic policies, gives rise to inequality and autocratic regimes and creates an environment for elites and politicians to abuse the revenues for their own personal interests. The combination of the resource richness and poor institutional quality mainly destroys accountability between governments and the citizens because the governments rely heavily on the revenues from the natural resources rather than the taxes from business-activities (King, 2009). The governments in those countries therefore tend to spend the revenues on military and interest-groups in order to protect their position and they don't have incentives to improve economic welfare and performance of the country. Leite and Weidman (1999) and Gylfason (2001) also showed natural resource richness gives rise to corruption and rent-seeking behavior, in turn, hamper economic growth by undermining resource allocation, economic efficiency and social equity. Isham et al. (2003) emphasized that particularly point-source natural resource dependency brings about poor public institutions by employing three-staged least squares estimations. Mehlum, Moene and Torvik (2006) showed that natural resource-abundant countries can benefit from it if they have producer friendly institutions. However, Brunnschweiler & Bulte (2008) showed resource abundance has a positive impact on economic growth and institutional quality but resource dependency has a negative one. Bhattacharyya and Hodler (2010) indicated that resource rents increase corruption in the countries lacking democratic institutions by using panel data analysis for the period 1980–2004 and 124 countries. Arezki and Brückner (2011) argued that oil rents have a strong effect on corruption in the countries with a high share of state participation in oil production by using panel data of 30 oil-exporting countries during the period 1992–2005. Sala-i-Martin & Subramanian (2003), Dietz et al. (2007), Arezki and Ploeg (2011), Moshiri and Hayati (2017), Zalle (2018) and Abdulahi et al. (2019) are among the other studies which suggest the institutional quality is a determinant factor on the relationship between economic growth and natural resource richness.

As for the crowding out channel, Gylfason (2004) argued that natural resource dependence can crowd out social, human, physical, foreign and real capitals. It is well-known that these capitals are strongly associated with economic growth. Indisputably, the crowd-out effect therefore hinders economic growth. By using the share of natural capital in total capital as an indicator for resource richness, he pointed out that a ten percent increase in natural capital share results in about four percent decrease in the trade openness indicator thereby brings about 0.3% decrease in gross domestic production (GDP) per capita. He also stressed the same amount of increase in the natural capital share creates a decrease in the foreign direct investment (FDI) index by 0.4 percent of GDP.

Social capital consists of culture, social cohesion, law, trust, the justice system, rules and customs in the country. Most of them are also related to the institutions in the country. Inequality can be considered as an indicator of social cohesion which is one of the components of social capital. There are many studies suggesting negative relationship between income inequality and natural resource richness, particularly in the developing and not developed countries (e.g., Leamer et al., 1999; Gylfason and Zoega, 2002; Ross, 2007; Howie and Atakhanova, 2014; Parcero and Papyrakis, 2016). Ross (2001a; 2003) maintained resource-rich developing countries perform poorly in regard to human development indicators, some political and institutional measurements. He also stated that poverty is even much more prevalent in those countries than the ones not having resource richness. Gylfason and Zoega (2002) claimed natural capital intensity has an adverse effect on economic growth directly alongside indirectly by reducing equality, secondary-school enrollment and investment rates. Bulte, Damania and Deacon (2005) reported that resource-rich countries tend to have a lower level of human development. Daniele (2011) claimed natural resource dependence is negatively associated with human development index level whilst resource abundance is positively associated with it.

Gylfason (2001, 2004) claimed that natural capital abundance seems to crowd out human capital and he also added the ignorance of education which is the most important determinant of that human capital to causes of the natural resource curse. Gylfason et al. (1999) stated that the abundance of natural resources and the corresponding primary production sectors (e.g., mining, agriculture, fisheries and forestry) need less human capital, so produce less human capital than the service and production sector. They showed with regression analysis that the abundance of natural resources crowds out human capital and thereby induces slow economic growth. Birdsall, Pinckney and Sabot (2001), Ross (2001a), Behbudi et al. (2010) are among the other studies which support this view. One of the recent studies, Cockx and Francken (2016) showed that natural resource dependence has a negative effect on public education expenditures by using panel data analysis covers 140 countries and the period 1995–2009. Cabrales and Hauk (2011) suggested that this relationship depends on the institutional quality of the country. Natural resource richness has a negative effect on human capital in countries where the institutional structure is weak while it has a positive one in the others.

As a key component of human capital, health is important for sustainable economic growth. Therefore, it is one of the subjects investigated in the literature on whether or not the huge revenues got from natural resources are used for improving public health. Ross (2001a) found a negative correlation between mineral and oil dependence and health expenditures. It was shown that oil-dependent countries perform worse than the countries with the same income level in terms of child and infant mortality and life expectancy at birth. Cockx and Francken (2014) showed that both natural resource abundance and dependence have a negative impact on health care expenditures by employing panel data analysis. De Soysa and Gizelis (2013) suggested resource curse is effective in spreading infectious diseases such as HIV/AIDS because natural resource-dependent countries tend to suffer from governance failures which in turn suffer lower-quality public health. They showed that the number of infected people increased as the share of oil and natural gas reserves increased by employing least square analysis and using 137 underdeveloped countries for the 1990–2008 period. Klautzer, Becker and Mattke (2014) showed that health expenditures per capita and human resources for health are considerably lower in the oil and gas-rich Gulf Cooperation Council (GCC) countries (Bahrain, Kuwait, Oman, Qatar, Saudi Arabia and the United Arab Emirates) when compared with OECD countries that have similar income levels with them. In contrast, some studies such as Cotet and Tsui (2013), Anshasy and Katsaiti (2015) and Sterck (2016) suggest there is no negative relationship between resource richness and public health care investments.

3. The reasons for the diversity in the empirical findings

After Auty (1993) popularized the resource curse hypothesis, Sachs and Warner (1995, 1997) analyzed the hypothesis empirically by using cross-sectional data of 97 developing countries. They found that a high share of primary-product (minerals and oil) exports in GDP resulted in low economic growth. While some studies found supporting results for the resource curse (e.g., Leite and Weidman, 1999; Dietz et al., 2007; Ross, 2001b; Sala-i-Martin & Subramanian, 2003; Mehlum et al., 2006; Moradbeigi, 2017; Damette and Seghir, 2018), some found that natural resource-richness increases economic growth (e.g., Davis, 1995; Stijns, 2006; Brunnschweiler, 2008; Alexeev and Conrad, 2011; Cavalcanti et al., 2011; Cotet and Tsui, 2013; Smith, 2015; Havranek et al., 2016; Ben-Salha et al., 2018). This diversity stems from resource richness indicator (that also defines resource abundance and dependence), resource type, econometric method, development level of the countries under analysis and the period analyzed. In literature, resource dependence which reflects the dependency of the countries on natural resources for growth and development is generally measured by the share of natural resource exports in GDP. Resource abundance is largely represented by stock values. Brunnschweiler and Bulte (2008) claimed that natural resource abundance has a positive effect on economic growth while natural resource dependence has a negative one on it. However, empirical literature suggests the effect is mixed. Readers are referred to Shahbaz et al. (2019) for the studies that indicate the evidence of positive and negative effects. Regarding the resource richness indicators, Sachs and Warner (1995, 1997) used the share of primary-product (minerals and oil) exports in GDP and total exports in the initial year, the share of mineral production in GDP and land per capita. Many researchers (e.g., Leite and Weidman, 1999; Sala-i-Martin & Subramanian, 2003; Mehlum et al., 2006; Brunnschweiler and Bulte, 2008; Kim and Lin, 2017) followed Sachs & Warner's method and used the share of primary-product (minerals and oil) in GDP in the initial year. The share of natural capital in total capital was used by Gylfason (2001), Stijns (2006), Cockx and Francken (2014). Wigley (2017) utilized oil income per capita. O'Connor et al. (2018) used oil and gas value per capita. Natural capital stock was used by Arezki and Ploeg (2011). The share of natural resource rents in GDP was used by Atkinson and Hamilton (2003), Collier and Hoeffler (2009), Bhattacharyya and Hodler (2010), De Soysa and Gizelis (2013), Bhattacharyya and Hodler (2014), Abdulahi et al. (2019) and Shahbaz et al. (2019). Arezki and Brückner (2011) and Arin and Braunfels (2018) used oil rents. Oil production per-capita and oil export per worker are used by Eregha and Mesagan (2016). Natural resource rents (Amiri et al., 2018; Dwumfour and Ntow-Gyamfi, 2018; Biresselioglu et al., 2019), natural resource rents per capita (Shahbaz et al., 2019), the real value of oil production (Cavalcanti et al., 2011), natural resource production data (Stijns, 2005; Smith, 2015; Bildirici and Gokmenoglu, 2019) are among the other indicators used for measuring natural resource richness.

Auty (2001) classified natural resources as point resources (e.g., oil and minerals) and diffuse resources (e.g., agricultural and forestry products). Isham et al. (2003) classified them as point resources, diffuse resources and coffee/cocoa. They found that point resources and coffee/cocoa abundance have a negative effect on institutions, which, in turn, a negative effect on economic growth while diffuse resources do not have any effect on it. Following Isham et al. (2003), Bulte et al. (2005) and Mavrotas et al. (2011) distinguished between point and diffuse resources. While the former claimed that only point resource-dependent countries perform worse economic growth performance than others, Mavrotas et al. (2011) found both point and diffuse-type resource dependency cause resource curse.

Point resources, linear cross-sectional regression and time series analysis (e.g., Sachs and Warner, 1995, 1997; 2001; Leite and Weidman, 1999; Sala-i-Martin & Subramanian, 2003; Stijns, 2005; Brunnschweiler and Bulte, 2008; Moshiri and Hayati, 2017) are generally used for investigating the resource curse. Linear panel data analysis has been mostly used in the recent decade (e.g., Bhattacharyya and Hodler, 2010; Arezki and Brückner, 2011; Cockx and Francken, 2014, 2016; Parcero and Papyrakis, 2016; Eregha and Mesagan, 2016; Apergis and Katsaiti, 2018; Ben-Salha et al., 2018). Although cross-sectional regression analysis provides supporting results for resource curse, the studies using panel regression analysis generally claim that natural resource richness has a positive impact on economic growth (Havranek et al., 2016). However, non-linear econometric analysis methods have been rarely used in the resource curse literature. One of them, Tiba (2019) applied the panel smooth transition regression model for 12 oil-exporting countries and found supporting results for the resource curse. Abdulahi, Shu and Khan (2019) utilized panel threshold model by using panel data of 14 resource-rich countries of sub-Saharan Africa and rule of law as a threshold value to identify threshold levels where resource rents positively/negatively affect economic growth.

4. DATA and econometric methods

4.1. Data

The precious metal production data was taken from U.S. Geological Survey Minerals Yearbooks. We included the countries with the highest production levels and adequate data as of 2017 in analysis, namely Australia, Canada Mexico, Peru, Philippines, South Africa and the USA. We had to exclude some precious metals, e.g., palladium, platinum, ruthenium, rhodium and iridium due to inadequate data for the analysis. GDP data was obtained from the World Bank database. All data covers the period of 1960–2017. Economic growth (y), gold production ($gold$), silver production (slv) and copper production (cop) are the variables under analysis. They were converted to log-ratio to reduce skewness as $ly = \log((y_t - y_{t-1})/y_{t-1}) lgold = \log((gold_t - gold_{t-1})/gold_{t-1})$, $lslv = \log((slv_t - slv_{t-1})/slv_{t-1})$ and $lcop = \log((cop_t - cop_{t-1})/cop_{t-1})$, where t and $t\text{-}1$ represent present value and the former value.

4.2. Econometric methods

We utilized STARDL model family developed by Bildirici and Ersin (2018) to investigate nonlinear long-run and short-run relationships between economic growth and precious metal productions. We conducted the BDS test developed by Brock et al. (1987) to check the linearity of the series before analyzing STARDL type cointegration relation.

4.3. BDS test

Brock et al. (1987) developed the BDS test to investigate if the series under study is independent and identically distributed (i.i.d.). The test also is successful at detecting neglected nonlinearity and other misspecification problems when applied to the residual derived from a linear time series (Bildirici and Turkmen, 2015). The test depends on correlation integral that is described for k-dimensional X_t time series $(t = 1, 2, \ldots, T)$ and $\{X_t\}_{t=1}^{T_k}$ observations as,

$$C_k(\delta) = \lim_{T_k \to \infty} \frac{2}{T_k(T_k - 1)} \sum_{i<j} I_\delta(X_i, X_j) \tag{1}$$

where $T_k = T - k + 1$ and $I_\delta(u, v)$ is an indicator function which equals one if $\|u - v\| < \delta$ and equals zero otherwise (Tsay, 2010, p. 208). The correlation integral is used to measure the fraction of data pairs being δ distant from each other. Considering a time series having k-history like $X_t^k = (x_t, x_{t+1}, \ldots, x_{t+k-1})'$, if the series has i.i.d. distribution, $C_k(\delta) = [C_1(\delta)]^k$ equation should be satisfied. Accordingly, the BDS test is formalized as

$$BDS_k(\delta, T) = \frac{\sqrt{T}\left\{C_k(\delta, T) - [C_1(\delta, T)]^k\right\}}{\sigma_k(\delta, T)}, \tag{2}$$

where $\sigma_k(\delta, T)$ is the standard deviation of $\sqrt{T}\{C_k(\delta, T) - [C_1(\delta, T)]^k\}$, readers are referred to Brock et al. (1987) for calculation.

4.4. STARDL models

STARDL model family developed by Bildirici and Ersin (2018) consists of Logistic Smooth Transition Autoregressive Distributed Lag (LSTARDL), Exponential Smooth Transition Autoregressive Distributed Lag (ESTARDL) and second-order LSTARDL (LSTAR2DL) models. These models are nonlinear Autoregressive Distributed Lag (ARDL) models, which are derived by augmenting the linear ARDL model developed by Pesaran et al. (2001) with the Smooth Transition Autoregressive (STAR) models developed by Terasvirta (1994). The linear ARDL model defined below is a single regime cointegration model,

$$\Delta y_t = \alpha_0 + \delta y_{t-1} + \beta x_{t-1} + \sum_{i=1}^{p} \alpha_i \Delta y_{t-i} + \sum_{i=0}^{m} \phi_i \Delta x_{t-i} + \varepsilon_t \tag{3}$$

where the variables can be either I(0) or I(1) or a mixture of both. In the model, δ and β are the long-run parameters, α_i and ϕ_i are the short-run parameters, Δ symbolizes the first differences and ε_t is an iid $(0\sigma^2)$ process. The long-run parameters can be also used for calculation of the long-run elasticities. Pesaran and Shin (1999) and Pesaran et al. (2001) developed an F-type test (F_{PSS}) to investigate the cointegration relationship in the model. Accordingly, the null hypothesis for no cointegration is described by

$$H_0 : \delta = 0, \beta = 0. \tag{4}$$

Pesaran et al. (2001) also developed an error correction model that is named restricted ARDL model to determine the speed of adjustment to long-run equilibrium as follow,

$$\Delta y_t = \omega_0 + \lambda ecm_{t-1} + \sum_{i=1}^{p} \alpha_i \Delta y_{t-i} + \sum_{i=0}^{m} \phi_i \Delta x_{t-i} + \varepsilon_t \tag{5}$$

where ecm_{t-1} is adapted from Engle and Granger's (1987) two-step cointegration approach. It stands for the lagged value of the residuals that are derived from $y_t = \alpha_0 + \beta x_t + \varepsilon_t$ cointegration relationship and formulated as $ecm_{t-1} = y_{t-1} - \alpha_0 - \beta x_{t-1}$. The coefficient of the ecm_{t-1} term, namely λ represents the speed of the adjustment back to long-run equilibrium. The expected value of the λ parameter is negative and bounded between 0 and 1 $(0 < |\lambda| < 1)$. If the requirements come true and the parameter is statistically significant, it can be said that the deviations from long-run equilibrium can be corrected.

The STAR models, which is presented as follow,

$$\begin{aligned} \Delta y_t = &\left(\alpha_{0,1} + \sum_{i=1}^{p} \alpha_{i,1} \Delta y_{t-i} + \sum_{i=0}^{m} \phi_{i,1} \Delta x_{t-i}\right) \\ &+ \left(\alpha_{0,2} + \sum_{i=1}^{p} \alpha_{i,2} \Delta y_{t-i} + \sum_{i=0}^{m} \phi_{i,2} \Delta x_{t-i}\right) \times F(\gamma; s_t, c) + \varepsilon_t, \end{aligned} \tag{6}$$

are the autoregressive models, where the transition between regimes is smooth. The transition process is governed by the transition function $F(\gamma; s_t, c)$ that is a continuous function bounded between 0 and 1. In the transition function, γ represents the speed of the transition, c symbolizes the threshold value, s_t is the transition variable which can be a lagged endogenous variable, exogenous variable, a linear function of lagged endogenous variables or time (t) (Dijk and Terasvirta, 2000).

The STARDL model that combines linear ARDL and STAR models is defined as follow:

$$\begin{aligned} \Delta y_t = &\left(\alpha_{0,1} + \delta_1 y_{t-1} + \beta_1 x_{t-1} + \sum_{i=1}^{p} \alpha_{i,1} \Delta y_{t-i} + \sum_{i=0}^{m} \phi_{i,1} \Delta x_{t-i}\right) \\ &+ \left(\alpha_{0,2} + \delta_2 y_{t-1} + \beta_2 x_{t-1} + \sum_{i=1}^{p} \alpha_{i,2} \Delta y_{t-i} + \sum_{i=0}^{m} \phi_{i,2} \Delta x_{t-i}\right) \times F(\gamma; s_t, c) + \varepsilon_t \end{aligned} \tag{7}$$

The model allows analyzing long-run and short-run dynamics in two separate regimes in which regime switching is taken place by the logistic or exponential transition functions. In the model, (δ_1, β_1) and (δ_2, β_2) are the long-run parameters in regime one and regime two, respectively while $\alpha_{1,1}, \alpha_{2,1}, \ldots, \alpha_{p,1}$, $\phi_{0,1}, \phi_{1,1}, \ldots, \phi_{m,1}$ are the short-run parameters in regime one and $\alpha_{1,2}, \alpha_{2,2}, \ldots, \alpha_{p,2}$ $\phi_{0,2}, \phi_{1,2}, \ldots, \phi_{m,2}$ are the short-run parameters in regime two. When transition function $(F(\gamma; s_t, c))$ is logistic, second-order logistic and exponential function, the model is called as LSTARDL, LSTAR2DL and ESTARDL model, respectively.

Bildirici and Ersin (2018) also developed a restricted version of the STARDL model that is nonlinear corresponding to equation (5) to investigate the error correction mechanism in case there is a STARDL type cointegration relationship. This model is named as Smooth Transition Autoregressive Distributed Lag – Error Correcting Model (STARDL-ECM) and given as,

$$\begin{aligned} \Delta y_t = &\left(\omega_{0,1} + \lambda_1 ecm_{t-1} + \sum_{i=1}^{p} \alpha_{i,1} \Delta y_{t-i} + \sum_{i=0}^{m} \phi_{i,1} \Delta x_{t-i}\right) \\ &+ \left(\omega_{0,2} + \lambda_2 ecm_{t-1} + \sum_{i=1}^{p} \alpha_{i,2} \Delta y_{t-i} + \sum_{i=0}^{m} \phi_{i,2} \Delta x_{t-i}\right) \times F(\gamma; s_t, c) + \varepsilon_t \end{aligned} \tag{8}$$

where λ_1 and λ_2 are the speed of the adjustment to long-run equilibrium in regime 1 and regime 2, respectively. The sign of them is expected to be negative and bounded between 0 and 1 $(0 < |\lambda| < 1)$as it is described for a linear restricted ARDL model. The main difference of STARDL-ECM model from STARDL one is that the previous one contains ecm_{t-1} term instead of long-run parameters in the latter. Accordingly, if transition function $(F(\gamma; s_t, c))$ is logistic, second-order logistic and exponential function, the model is called as LSTARDL-ECM, LSTAR2DL-ECM and ESTARDL-ECM model, respectively. We utilized modeling approach of Terasvirta (1994) to determine transition function as in Bildirici and Ersin (2018). For detailed information, readers are referred to Terasvirta (1994) and Bildirici and Ersin (2018).

STARDL modeling procedure that is developed by Bildirici and Ersin (2018) can be summarized as follows:

1. Model specification step: In this step, the linear ARDL model is tested against the STARDL-type nonlinear model. Accordingly, the null hypothesis is $H_0 : \gamma = 0$ and the alternative one is $H_1 : \gamma > 0$. Lagrange Multiplier (LM) type tests that are developed by Luukkonen et al. (1988), Granger and Terasvirta (1993) and Terasvirta (1994) are used for testing the hypothesis. To determine the transition function, Bildirici and Ersin (2018) suggested utilizing Wald-type tests rather than Taylor expansions and using diagnostic tests on the estimated model.

2. Estimation and testing step: STARDL models are estimated by using Nonlinear Least Squares (NLS) method. The threshold values are also estimated at this step. After the estimation, Wild-type block tests of Pesaran et al. (2001) that are extended to nonlinear STARDL models are used to test linear/nonlinear cointegration relations. Accordingly, the null hypothesis which suggests no linear/nonlinear cointegration for equation (7):

$$H_0 : \delta_1 = 0, \beta_1 = 0, \delta_2 = 0, \beta_2 = 0 \tag{9}$$

and alternative hypothesis suggesting STARDL type cointegration:

$$H_1 : \delta_1 \neq 0, \beta_1 \neq 0, \delta_2 \neq 0, \beta_2 \neq 0 \tag{10}$$

When the null hypothesis is rejected, to differentiate between linear (one regime) and nonlinear (two regimes) cointegration, the long-run parameters in both regimes should be analyzed. To this end, Bildirici and Ersin (2018) suggested two alternative hypothesizes against the null hypothesis as follows:

$$H_{1,r1} : \delta_1 \neq 0, \beta_1 \neq 0, \tag{11}$$

$$H_{1,r2} : \delta_2 \neq 0, \beta_2 \neq 0 \tag{12}$$

Alternatively, they also developed Wald tests for testing symmetric and asymmetric cointegration as follows:

$$H_{0,lr\_symmetry} : \delta_1 = \delta_2, \beta_1 = \beta_2 \tag{13}$$

$$H_{1,\mathrm{lr\_asymmetry}} : \delta_1 \neq \delta_2, \beta_1 \neq \beta_2 \tag{14}$$

$H_{0,lr\_symmetry}$ null hypothesis is used for testing long-run symmetric, namely single-regime cointegration, the alternative hypothesis, $H_{1,\mathrm{lr\_asymmetry}}$, is used for long-run asymmetric relationship. If $H_{1,r1}$ hypothesis is accepted while $H_{1,r2}$ one is rejected or if $H_{1,r1}$ hypothesis is rejected but $H_{1,r2}$ one is accepted, it can be concluded that the cointegration relation is linear. In case the alternative hypothesizes in equations (10)–(12) or those in equations (10) and (14) cannot be rejected, it can be decided that the cointegration relation is STARDL-type.

5. Empirical results

We conducted empirical analysis in four steps. In the first step, we applied linear unit root, stationary tests and STAR type unit root test to check if the series is not integrated of order two (I(2)) or above since Pesaran et al. (2001) provided critical values only for integrated of order zero (I(0)) or order one (I(1)) series. In the second step, we utilized the BDS test to check if the series is nonlinear or not. Besides the BDS test, we also applied linearity test against STARDL type nonlinearity. In the third step, we estimated the model with NLS. In the fourth step, we analyzed STARDL type cointegration relation. In the fifth step, we applied the remaining STAR nonlinearity test that is developed by Terasvirta (1994) to check if there is a remaining nonlinearity.

5.1. Unit root test results

The linear Augmented Dickey-Fuller (ADF) unit root test, Kwiatkowski-Phillips-Schmidt-Shin (KPSS) stationary test and STAR type Kapetanios-Shin-Snell (KSS) (Kapetanios et al., 2003) unit root test were applied to determine the integration order of the series. The results are presented in Table 1. According to ADF linear unit root test results, for the level values of all series, the null hypothesis suggesting that there is a unit root cannot be rejected at the conventional significance levels. However, the same null hypothesis can be rejected when the test is applied to the first difference of the series. As for the results of the KPSS stationary test that takes into consideration structural breaks in the series, the null hypothesis suggesting stationary of the series cannot be accepted for the level values of all series but it can be accepted for the first difference of the series. Regarding the STAR-type nonlinear KSS unit root test results, the null hypothesis indicating there is a unit root in the series cannot be rejected at the level of the series, but it can be rejected when applied to the first difference of all series. Consequently, it is concluded that all series under study follows integrated of order one (I) process.

5.2. BDS test results

We applied the BDS test that is discussed in the previous section to check the nonlinearity of the series under study. The test was applied to the level and the first difference of the series. According to results in Table 2, all BDS and *z* statics that were derived from the test is greater than the critical values for all series, which means rejecting the null hypothesis of independent and identically distributed (i.i.d.) and therefore accepting the nonlinearity of the all level and first differenced series.

5.3. STARDL type nonlinearity test results

The linearity test against STARDL model also includes selecting transition variables and transition functions. The test is based on the LM testing method developed by Luukkonen et al. (1988), Granger and Terasvirta (1993) and Terasvirta (1994). In this step, the linearity test against STARDL model was repeated by using every first differenced variable $(\Delta ly_{t-1}, \ldots, \Delta ly_{t-p}; \Delta lgold_{t-1}, \ldots, \Delta lgold_{t-q}; \Delta lslv_{t-1}, \ldots, \Delta lslv_{t-m};\ \Delta lcop_{t-1}, \ldots, \Delta lcop_{t-n})$ as a candidate transition variable. The optimum transition variables and transition functions were selected according to lowest *F*-probability. Accordingly, LSTARDL and LSTAR2DL are the best two models giving lowest *F*-probability that means strongly rejecting linearity. At this point, we followed the approach suggested by Bildirici and Ersin (2018) and estimated the best two models at the same time. Afterward, we determined STARDL model structure by comparing explanatory powers of the estimated models.

5.4. STARDL models

The estimated STARDL models are presented in Tables 3–9. They contain both unrestricted LSTAR(2)DL and restricted LSTAR(2)DL-ECM models. STARDL-type Pesaran et al. (2001) cointegration test and error correction test results are provided at the bottom of every table. The cointegration test was applied for the overall model and every regime, and corresponding *F* statics were symbolized as $F_{PSS,\ overall}$, $F_{PSS,\ Regime\ 1}$ and $F_{PSS,\ Regime\ 2}$. In the models, regime 1 and regime 2 represent crisis and growth phases of the economy, respectively. We used critical values that were provided by Narayan and Narayan (2005) for the bound test for case 2 (intercept and no trend). Accordingly, these are [3.280, 2.345], [3.813, 2.763] and [4.947, 3.738] for 10%, 5% and 1% significance level, respectively for Australia, Canada, Mexico and Peru. The values are [3.356, 2.508], [3.942, 2.982] and [5.200, 4.118] for Philippines and USA, and [3.532, 2.618], [4.194, 3.164] and [5.816, 4.428] for South Africa for the same significance levels.

Table 1

Unit root test results.

Variables	Australia			Canada			Mexico			Peru		
	ADF	KPSS	KSS	ADF	KPSS	KSS	ADF	KPSS	KSS	ADF	KPSS	KSS
ly_t	−2.05	0.134*	−0.55(C3)	−1.17	0.222***	−1.96 (C3)	−1.16	0.256***	−1.18(C3)	−1.45	0.156**	−2.61(C3)
dly_t	−5.81***	0.105	−12.45*** (C1)	−4.71***	0.075	−9.98*** (C1)	−5.61***	0.089	−2.62** (C1)	−4.37***	0.088	−17.1*** (C1)
$lcop_t$	−2.14	0.186**	−1.75(C1)	−2.75	0.195**	−1.62 (C1)	−3.01	0.248***	−2.68(C3)	−2.92	0.199**	−1.85(C2)
$dlcop_t$	−7.11***	0.101	−16.55*** (C1)	−7.14***	0.109	−9.45*** (C1)	−5.37***	0.049	−5.99*** (C1)	−8.67***	0.075	−9.15*** (C2)
$lgold_t$	−1.86	0.268***	−2.35(C2)	−2.73	0.137*	−0.62 (C2)	−1.19	0.296***	−1.41(C3)	−1.42	0.186**	−1.61(C1)
$dlgold_t$	−4.14***	0.071	−5.79*** (C2)	−3.89**	0.045	−8.58*** (C2)	−6.23***	0.067	−7.81*** (C1)	−5.53***	0.046	−18.2*** (C1)
$lslv_t$	−2.51	0.155**	−2.99(C3)	−1.95	0.192**	−1.75 (C2)	−1.25	0.139*	−1.01(C1)	−2.12	0.171**	−2.33(C3)
$dlslv_t$	−7.75***	0.036	−7.97*** (C1)	−5.62***	0.096	−10.14*** (C2)	−6.17***	0.083	−13.62*** (C1)	−9.37***	0.082	−6.97*** (C1)

	Philippines			South Africa			USA		
	ADF	KPSS	KSS	ADF	KPSS	KSS	ADF	KPSS	KSS
ly_t	−1.36	0.156**	−1.26(C3)	−2.07	0.164**	−1.67(C3)	−2.01	0.199**	−1.83(C3)
dly_t	−3.95***	0.033	−11.56***(C1)	−3.87**	0.049	−7.86***(C1)	−6.17***	0.071	−17.41***(C1)
$lcop_t$	−1.85	0.165**	−1.95(C3)	−1.93	0.251***	−2.45(C2)	−2.53	0.202**	−1.59(C1)
$dlcop_t$	−5.35***	0.074	−10.20***(C1)	−7.18***	0.096	−4.81***(C2)	−7.66***	0.062	−11.86***(C1)
$lgold_t$	−1.27	0.152**	−1.87(C1)	−1.96	0.242***	−0.09(C1)	−1.91	0.168**	−1.03(C1)
$dlgold_t$	−7.02***	0.062	−10.08***(C1)	−4.29***	0.083	−8.17***(C1)	−3.61**	0.056	−14.14***(C1)
$lslv_t$				−1.28	0.222***	−1.62(C2)	−1.65	0.197**	−0.56(C1)
$dlslv_t$				−7.51***	0.099	−3.33**(C2)	−5.91***	0.091	−9.38****(C1)

ADF and KPSS tests are calculated for intercept + trend assumption. Critical Values for ADF test: 1% level: 4.137279, 5% level: 3.495295, 10% level: 3.176618; for KPSS test: 1% level: 0.216, 5% level: 0.146, 10% level: 0.119; for KSS test C(1) 1% level: 2.82, 5% level: 2.22, 10% level: 1.92; C(2) 1% level: 3.48, 5% level: 2.93, 10% level: 2.66; C(3) 1% level: 3.93, 5% level: 3.40, 10% level: 3.13. Cases 1, 2, and 3 (C1, C2, and C3) represent raw, demeaned, and detrended data selections, respectively. 1%, 5% and 10% significance levels are denoted by ***,**,* respectively.

$F_{ecm,\ Regime\ 1}$ and $F_{ecm,\ Regime\ 2}$ statics are the F statics used for testing the null hypothesis suggesting that the error correction term is zero for the corresponding regimes, separately. The alternative hypothesis indicates that the error correction term is negative and statistically significant. Besides, $F_{ecm,\ overall}$ statics was used for testing the error correction terms in both regimes are zero jointly. LSTARDL-ECM and LSTAR2DL-ECM models have error correction terms in place of level variables (*ly, lgold, lslv* and *lcop*).

At the goodness of fit and diagnostic test section of the tables, Q(1,2) test statics are the first and second-order Ljung-Box test statics and used for testing whether the residuals have autocorrelation or not. All Q(1,2) statics in Tables 3–9 suggest there are no autocorrelations in the residuals. The ARCH-LM test statics were used for investigating the ARCH effect in the residuals. The ARCH effect that is also considered as an indicator for remaining nonlinearity in the residuals were rejected for all models at classical significance levels. Besides, we checked remaining STAR nonlinearity in the residual by F tests based on the LM tests of Terasvirta (1994). The results were reported as *F(STAR)* that stands for the p-value of the remaining STAR-type nonlinearity test. Accordingly, remaining nonlinearity was rejected for all models of all countries at the 5% significance level. This result shows the efficiency of both LSTAR2DL and LSTARDL models. In conclusion, the diagnostic and goodness of fit test results indicate both LSTAR2DL and LSTARDL models are suitable for investigating the nonlinear relationship between economic growth and precious metal productions. To determine the best model, we utilized R^2 value that is used for detecting the explanatory power of the model.

The analysis results for Australia are presented in Table 4. According to R^2 values, explanatory powers of LSTAR2DL and LSTARDL models are the same. As for the unrestricted versions of the models, LSTARDL-ECM has a higher R^2 value than LSTAR2DL-ECM, suggesting a better fit for the former. STARDL-type cointegration test for the whole model was tested with $F_{PSS,\ overall}$ bound test static, and it was estimated 16.36 for LSTAR2DL model and 9.2 for LSTARDL model. The values are over the upper bound critical value (4.94) at a 1% significance level, meaning that rejecting the null hypothesis suggesting no cointegration. The regime specific cointegration was tested with $F_{PSS,\ Regime\ 1}$, $F_{PSS,\ Regime\ 2}$, and they are 10.84 and 21.87 for LSTAR2DL model and 8.85 and 9.42 for LSTARDL model. These results also suggest rejecting null hypothesis representing no cointegration as they are over the upper bound critical value at 1% significance level. For the restricted counterparts of the models, namely LSTAR2DL-ECM and LSTARDL-ECM, $F_{ecm,\ overall}$ statics were estimated as 26.54 and 13.04, respectively. Thus, we can reject the null hypothesis suggesting no error correction mechanism towards long-run at 1% significance level for the whole model. $F_{ecm,\ Regime\ 1}$ and $F_{ecm,\ Regime\ 2}$ statics used for deciding if regime specific error correction mechanism exists are 44.62 and 8.46 for LSTAR2DL-ECM model and 11.91 and 12.56 for LSTARDL-ECM model, which leads to rejection of the null hypothesis of no error correction mechanism in the models.

The threshold parameters were estimated as −0.089 and + 0.089 for LSTAR2DL model and −0.045 and + 0.045 for LSTAR2DL-ECM model. The transition speed is −8.58 for LSTAR2DL model and −7.99 for LSTAR2DL-ECM model, meaning that transition from one regime to another is smooth. The second lag of economic growth (dly_{t-2}) was determined as the optimum transition variable for both models. Hence, when the growth rate is smaller than −0.089 or bigger than +0.089, the second-order logistic function approaches 1 and the outer regimes (regime 2) become dominant. If the transition variable between two threshold parameters ($-0.089 < dly_{t-2} < +0.089$), regime 1 becomes dominant. In LSTAR2DL model, the long run elasticities (*lre)* were calculated as 4.75 in regime 1 and -0.25 in regime 2 for copper production, meaning a 1% increase in copper production gives rise to 4.75% increase in economic growth in regime 1 and 0.25% decrease in regime 2. As for the gold production, the elasticities are 0.64 and 0.10 for regime 1 and regime 2, indicating the effect of gold production is higher in regime 1. According to calculated *lre* for silver production, 1% increase in silver production induces 2.28% increase in economic growth in regime 1 and 0.16% increase in regime 2.

In LSTAR2DL-ECM model, the coefficients of the ecm_{t-1} terms were estimated as −0.32 and −0.22 for regime 1 and regime 2, respectively, indicating an error correcting mechanism in the system. As for short-run dynamics in LSTAR2DL model, a 1% increase in copper production

Table 2
BDS test results.

Australia

	ly_t			dly_t			$lcop_t$			$dlcop_t$			$lgold_t$		
Dim.	BDS	z	P	BDS	z	p	BDS	z	P	BDS	z	p	BDS	Z	p
2	0.203	36.07	0.00	0.019	2.08	0.00	0.164	27.54	0.00	0.022	3.96	0.00	0.173	26.61	0.00
3	0.342	38.06	0.00	0.023	2.65	0.00	0.283	29.90	0.00	0.015	3.34	0.00	0.289	27.74	0.00
4	0.439	40.89	0.00	0.016	2.61	0.00	0.365	32.44	0.00	0.012	4.14	0.00	0.361	38.84	0.00
5	0.510	45.31	0.00	0.010	2.58	0.00	0.419	35.77	0.00	0.011	7.05	0.00	0.404	30.71	0.00
6	0.561	51.53	0.00	0.004	2.06	0.00	0.453	40.23	0.00	0.009	11.56	0.00	0.426	33.31	0.00

	$dlgold_t$			$lslv_t$			$dlslv_t$		
Dim.	BDS	z	P	BDS	z	p	BDS	z	p
2	0.053	4.38	0.00	0.171	27.75	0.00	0.021	2.25	0.02
3	0.061	4.72	0.00	0.289	29.34	0.00	0.028	2.14	0.03
4	0.043	4.17	0.00	0.364	30.80	0.00	0.037	2.73	0.00
5	0.032	4.35	0.00	0.412	33.23	0.00	0.041	3.36	0.00
6	0.021	4.48	0.00	0.440	36.54	0.00	0.035	3.40	0.00

Canada

	ly_t			dly_t			$lcop_t$			$dlcop_t$			$lgold_t$		
Dim.	BDS	z	p	BDS	z	p	BDS	z	P	BDS	z	p	BDS	Z	p
2	0.204	29.73	0.00	0.018	4.13	0.00	0.094	17.91	0.00	0.001	1.55	0.00	0.174	22.71	0.00
3	0.347	31.52	0.00	0.012	3.31	0.00	0.091	19.99	0.00	0.002	1.17	0.00	0.286	23.24	0.00
4	0.447	33.85	0.00	0.010	3.97	0.00	0.065	21.82	0.00	0.001	2.40	0.00	0.358	24.19	0.00
5	0.519	37.38	0.00	0.009	6.36	0.00	0.044	25.89	0.00	0.001	3.74	0.00	0.401	25.65	0.00
6	0.570	42.30	0.00	0.007	9.51	0.00	0.028	31.10	0.00	0.0005	4.05	0.00	0.417	27.38	0.00

	$dlgold_t$			$lslv_t$			$dlslv_t$		
Dim.	BDS	z	p	BDS	z	p	BDS	z	p
2	0.052	7.76	0.00	0.143	10.48	0.00	0.004	2.36	0.00
3	0.048	7.78	0.00	0.189	11.60	0.00	0.003	2.80	0.00
4	0.036	8.45	0.00	0.194	13.19	0.00	0.003	6.94	0.00
5	0.028	10.69	0.00	0.182	15.75	0.00	0.003	21.47	0.00
6	0.020	14.07	0.00	0.162	19.16	0.00	0.002	48.59	0.00

Mexico

	ly_t			dly_t			$lcop_t$			$dlcop_t$			$lgold_t$		
Dim.	BDS	z	p	BDS	z	p	BDS	z	P	BDS	Z	p	BDS	Z	p
2	0.205	26.43	0.00	0.039	3.87	0.00	0.149	11.86	0.00	0.054	3.24	0.00	0.185	16.49	0.00
3	0.351	28.12	0.00	0.055	4.81	0.00	0.246	12.16	0.00	0.102	3.77	0.00	0.252	16.33	0.00
4	0.453	30.19	0.00	0.045	4.10	0.00	0.305	12.44	0.00	0.127	3.87	0.00	0.305	16.44	0.00
5	0.526	33.27	0.00	0.025	2.87	0.00	0.345	13.28	0.00	0.136	3.94	0.00	0.339	17.35	0.00
6	0.578	37.55	0.00	0.020	2.45	0.00	0.368	14.41	0.00	0.122	3.59	0.00	0.359	18.85	0.00

	$dlgold_t$			$lslv_t$			$dlslv_t$		
Dim.	BDS	Z	p	BDS	z	p	BDS	z	p
2	0.050	8.39	0.00	0.148	16.75	0.00	0.048	4.60	0.00
3	0.041	8.01	0.00	0.244	17.11	0.00	0.042	4.10	0.00
4	0.029	7.58	0.00	0.303	17.59	0.00	0.037	3.26	0.00
5	0.023	6.88	0.00	0.335	18.46	0.00	0.045	4.30	0.00
6	0.018	6.53	0.00	0.355	20.03	0.00	0.032	3.01	0.00

Peru

	ly_t			dly_t			$lcop_t$			$dlcop_t$			$lgold_t$		
Dim.	BDS	Z	p	BDS	z	p	BDS	z	P	BDS	Z	p	BDS	Z	p
2	0.181	19.67	0.00	0.036	2.79	0.00	0.169	19.22	0.00	0.024	5.06	0.00	0.190	28.43	0.00
3	0.297	19.98	0.00	0.061	2.93	0.00	0.281	19.77	0.00	0.016	4.50	0.00	0.317	29.80	0.00
4	0.373	20.73	0.00	0.061	2.44	0.00	0.353	20.61	0.00	0.014	4.14	0.00	0.402	31.70	0.00
5	0.424	22.25	0.00	0.059	2.23	0.00	0.396	21.86	0.00	0.010	3.05	0.00	0.458	34.65	0.00
6	0.456	24.50	0.00	0.060	2.28	0.00	0.421	23.76	0.00	0.009	8.56	0.00	0.495	38.80	0.00

	$dlgold_t$			$lslv_t$			$dlslv_t$		
Dim.	BDS	Z	p	BDS	z	p	BDS	z	p
2	0.049	8.09	0.00	0.167	23.87	0.00	0.046	4.40	0.00
3	0.038	7.41	0.00	0.279	24.92	0.00	0.043	4.15	0.00
4	0.034	7.08	0.00	0.355	26.48	0.00	0.036	3.16	0.00
5	0.027	6.25	0.00	0.407	28.93	0.00	0.025	3.03	0.00
6	0.014	5.53	0.00	0.443	32.47	0.00	0.023	3.01	0.00

Philippines

(*continued on next page*)

Table 2 (*continued*)

Philippines

	ly$_t$			dly$_t$			lcop$_t$			dlcop$_t$			lgold$_t$		
Dim.	BDS	Z	p	BDS	z	p	BDS	z	p	BDS	z	p	BDS	Z	p
	ly$_t$			dly$_t$			lcop$_t$			dlcop$_t$			lgold$_t$		
Dim.	BDS	Z	p	BDS	z	p	BDS	z	p	BDS	z	p	BDS	Z	p
2	0.195	28.72	0.00	0.040	3.98	0.00	0.175	26.73	0.00	0.024	4.51	0.00	0.149	27.44	0.00
3	0.325	29.79	0.00	0.054	4.41	0.00	0.290	27.59	0.00	0.021	3.00	0.00	0.241	27.90	0.00
4	0.417	31.80	0.00	0.042	4.01	0.00	0.358	28.33	0.00	0.022	3.10	0.00	0.289	28.04	0.00
5	0.483	34.97	0.00	0.033	3.87	0.00	0.395	29.74	0.00	0.024	4.59	0.00	0.304	28.26	0.00
6	0.535	39.70	0.00	0.025	4.45	0.00	0.408	31.60	0.00	0.019	5.71	0.00	0.313	30.11	0.00

	dlgold$_t$		
Dim.	BDS	z	p
2	0.040	2.86	0.00
3	0.065	2.85	0.00
4	0.075	2.74	0.00
5	0.062	2.45	0.00
6	0.059	2.39	0.00

South Africa

	ly$_t$			dly$_t$			lcop$_t$			dlcop$_t$			lgold$_t$		
Dim.	BDS	z	p	BDS	z	p	BDS	z	p	BDS	z	p	BDS	Z	p
2	0.197	25.81	0.00	0.030	3.54	0.00	0.195	23.74	0.00	0.055	4.20	0.00	0.215	20.67	0.00
3	0.333	27.15	0.00	0.052	3.80	0.00	0.266	32.22	0.00	0.051	4.02	0.00	0.304	27.17	0.00
4	0.427	28.94	0.00	0.064	3.90	0.00	0.288	46.57	0.00	0.047	4.19	0.00	0.339	37.53	0.00
5	0.499	32.06	0.00	0.063	3.65	0.00	0.289	70.80	0.00	0.025	3.32	0.00	0.348	54.62	0.00
6	0.553	36.43	0.00	0.054	3.20	0.00	0.279	112	0.00	0.011	2.05	0.00	0.350	83.82	0.00

	dlgold$_t$			lslv$_t$			dlslv$_t$		
Dim.	BDS	z	p	BDS	z	p	BDS	z	p
2	0.041	7.45	0.00	0.178	28.49	0.00	0.029	2.45	0.00
3	0.040	8.29	0.00	0.249	41.14	0.00	0.028	2.22	0.00
4	0.030	9.53	0.00	0.278	63.17	0.00	0.032	2.61	0.00
5	0.020	10.89	0.00	0.278	99.43	0.00	0.040	3.28	0.00
6	0.012	12.68	0.00	0.268	162.72	0.00	0.031	2.89	0.00

USA

	ly$_t$			dly$_t$			lcop$_t$			dlcop$_t$			lgold$_t$		
Dim.	BDS	z	p	BDS	z	p	BDS	z	P	BDS	z	p	BDS	Z	p
2	0.203	36.43	0.00	0.020	2.43	0.01	0.079	28.92	0.00	0.056	4.47	0.00	0.185	33.24	0.00
3	0.343	38.46	0.00	0.030	3.836	0.00	0.086	37.17	0.00	0.057	4.18	0.00	0.312	35.12	0.00
4	0.441	41.28	0.00	0.019	3.553	0.00	0.071	47.96	0.00	0.047	4.19	0.00	0.393	37.14	0.00
5	0.510	45.55	0.00	0.009	2.753	0.00	0.051	63.05	0.00	0.027	3.32	0.00	0.442	39.97	0.00
6	0.560	51.57	0.00	0.004	2.505	0.00	0.032	77.26	0.00	0.012	2.21	0.02	0.468	43.87	0.00

	dlgold$_t$			lslv$_t$			dlslv$_t$		
Dim.	BDS	z	p	BDS	z	p	BDS	z	p
2	0.055	4.30	0.00	0.110	12.03	0.00	0.022	2.27	0.01
3	0.046	2.68	0.00	0.126	13.35	0.00	0.026	2.02	0.01
4	0.037	2.47	0.01	0.103	14.18	0.00	0.038	2.76	0.00
5	0.026	2.31	0.02	0.075	15.47	0.00	0.040	3.02	0.00
6	0.026	3.22	0.00	0.047	15.40	0.00	0.036	3.20	0.00

brings about 0.50% increase in economic growth in regime 1 while it has a negative effect, 0.50% decrease, in regime 2. The effect of a 1% increase in gold production was estimated as 1.46% for regime 1 and -0.09% for regime 2, meaning it has a negative effect on the second regime. The same amount increase in silver production induces 0.82% increase in economic growth in regime 1 and 0.21% decrease in economic growth in regime 2. In LSTAR2DL-ECM model structure, the short-run effects of the precious metals on economic growth are positive in regime 1 while it is negative in other regimes.

For LSTARDL and LSTARDL-ECM models, thresholds parameters were estimated as −0.099 and transition variables were estimated as the first lag of the gold production growth rate ($dlgold_{t-1}$). Accordingly, when the first lag of gold production growth rate exceeds −0.099, transition function approaches to 1 and the economy moves to regime 2. In other case ($dlgold_{t-1} < -0.099$), the function approaches to 0 and regime 1 prevails. The transition speeds are smooth as in LSTAR2DL models. The long run elasticities of copper production are negative in both regimes indicating that the production has a negative effect on Australia's economy. Yet they are positive for gold and silver productions. If we evaluate the long-run elasticities of silver production, we can say a 1% increase in the production gives rise to a 2.6% increase in economic growth in regime 1 and 1.19% one in regime 2. For gold production, *lre* is higher in regime 2 (0.69) than regime 1 (0.37). In LSTARDL-ECM model, the coefficients of ecm_{t-1} terms were estimated as −0.22 in regime 1 and -0.33 in regime 2, indicating that 22% of the deviations from the long-run are corrected in regime 1 and 22% of them are corrected in regime 2 in one period. Regarding the short-run dynamics in LSTARDL model, a 1% increase in copper production brings about

Table 3
Australia, LSTAR(2)DL and LSTAR(2)DL-ECM models.

Models:	LSTAR2DL		LSTAR2DL-ECM		LSTARDL		LSTARDL-ECM	
Long-run Coefficients	Regime 1	Regime 2	Regime 1	Regime 2	Regime 1	Regime 2	Regime 1	Regime 2
ly$_{t-1}$	0.571*** (3.93)	0.025*** (2.98)			−0.281*** (−3.71)	0.381*** (3.66)		
lcop$_{t-1}$	0.12** (2.61)	−0.099*** (−6.68)			0.38*** (2.57)	−0.197*** (−2.98)		
lslv$_{t-1}$	0.25*** (2.38)	0.155*** (3.89)			0.136*** (2.85)	0.32*** (2.98)		
lgold$_{t-1}$	0.88*** (3.91)	0.23*** (4.44)			0.749*** (2.98)	0.55*** (2.92)		
L.R.E.:cop	4.75	−0.25			−0.74	−1.93		
L.R.E.:slv	2.28	0.16			2.06	1.19		
L.R.E.:gold	0.64	0.10			0.37	0.69		
Error Correction Terms:								
ecm $_{t-1}$			−0.32*** (6.69)	−0.22*** (−2.93)			−0.229*** (−3.46)	−0.338*** (−3.59)
Short-run Coefficients								
dly$_{t-1}$	0.49** (1.995)	−0.822*** (−2.59)	−1.36*** (−2.91)	1.31** (2.19)	0.678*** (2.61)	0.797*** (3.36)	0.121*** (3.08)	0.238** (2.043)
dly$_{t-2}$	0.838*** (2.57)	0.567** (2.24)	−1.08*** (−3.28)	0.261*** (2.48)	0.122*** (2.75)	−0.774** (−2.28)	0.69** (2.29)	−0.211** (−2.36)
dlcop$_{t-1}$	0.127** (2.19)	−0.29** (−2.18)	1.55** (2.44)	−1.33** (−2.29)	−0.31** (−1.88)	0.836*** (5.38)	−0.281** (−2.39)	0.87*** (3.76)
dlcop$_{t-2}$	0.381*** (3.42)	−0.211*** (−3.65)	0.55*** (3.34)	−0.111*** (3.33)	−0.73*** (−3.79)	0.247*** (4.58)	−0.387*** (−3.78)	0.52*** (2.98)
dlslv$_{t-1}$	0.271** (2.19)	0.077 (0.09)	0.251*** (2.88)	−0.361** (−2.25)	0.28*** (2.77)	−0.25*** (−2.98)	0.558*** (3.77)	−0.45*** (−3.39)
dlslv$_{t-2}$	0.55*** (5.57)	−0.288** (−2.41)	1.399*** (4.37)	−1.09*** (−3.29)	0.77*** (3.91)	−0.44** (−2.06)	0.193* (1.63)	−0.228** (1.98)
dlgold$_{t-1}$	0.541*** (4.49)	−0.47*** (−3.88)	1.24*** (4.15)	−0.318*** (−3.77)	0.81*** (6.27)	0.82*** (2.44)	0.44*** (2.67)	−0.35*** (−2.719)
dlgold$_{t-2}$	0.92*** (7.90)	0.388*** (−5.35)	3.182*** (6.49)	−0.71*** (−3.79)	0.198 (0.382)	0.44*** (3.81)	0.561*** (7.38)	0.229 (0.794)
Cons	0.141*** (3.75)	0.032*** (3.78)	0.01** (2.25)	−0.081*** (0.91)	0.09** (2.176)	−0.78*** (−2.58)	−0.0082 (−0.11)	−0.023 (0.41)
γ	−8.58** (−4.32)		−7.99** (−1.98)		−9.089** (−1.99)		−11.99** (−1.99)	
C	−0.089***, +0.089*** (−6.34, +6.34)		−0.045***, +0.045*** (−6.17, +6.17)		−0.099*** (−2.78)		−0.099*** (−2.78)	
s$_t$	dly$_{t-2}$		dly$_{t-2}$		dlgold$_{t-1}$		dlgold$_{t-1}$	

Goodness of fit and diagnostics tests:				
Models:	LSTAR2DL	LSTAR2DL-ECM	LSTARDL	LSTARDL-ECM
R^2	0.63	0.62	0.63	0.66
Adj. R^2	0.58	0.58	0.57	0.59
Q(1–2)	0.18[0.91]	0.11[0.94]	0.36[0.81]	0.45[0.50]
ARCH (1–2)	2.21[0.14]	2.165[0.15]	2.50[0.22]	2.88[0.21]
F (STAR)	0.15	0.22	0.36	0.12
Regime specific, Overall (joint tests in both regimes) Error Correction Tests:				
	F$_{PSS,\ Regime\ 1}$ = 10.84475[0.00] F$_{PSS,\ Regime\ 2}$ = 21.8744[0.00] F$_{PSS,\ overall}$ = 16.36108[0.00]	F$_{ecm,\ Regime\ 1}$ = 44.6224[0.00] F $_{ecm,\ Regime\ 2}$ = 8.4681[0.04] F $_{ecm,\ overall}$ = 26.5452[0.00]	F$_{PSS,\ Regime\ 1}$ = 8.850[0.004] F$_{PSS,\ Regime\ 2}$ = 9.425[0.004] F$_{PSS,\ overall}$ = 9.10[0.004]	F $_{ECM\ TERM,\ Regime\ 1}$:11.91[0.000] F$_{ECM\ TERM,\ Regime\ 2}$:12,56[0.000] F$_{ECM,\ OVERALL}$:13.04[0.000]

0.94% decrease in economic growth in regime 1 and 1.08% increase in regime 2. The same amount increase in silver production gives rise to a 1.05% increase in economic growth in regime 1 and 0.69% decrease in regime 2. Gold production growth has positive effects on Australia's economy in both regimes. In sum, copper production has a negative effect on Australia's economy in the long run while other precious metals have positive ones in both models. In the short run, the effects of all precious metals are positive in crisis but they are negative in the growth phase of the economy in LSTAR2DL model while the effect is various for LSTARDL model.

The test results for the Philippines are presented in Table 5. According to the R^2 values, LSTAR2DL model is the best model describing the Philippines' economy. Estimated $F_{PSS,\ overall}$ statics are 9.70 and 12.11 for LSTAR2DL and LSTARDL model, respectively. As they are higher than the upper bound critical value at 1% level, the null hypothesis of no cointegration can be clearly rejected for each model. As for individual regimes, $F_{PSS,\ Regime\ 1}$ and $F_{PSS,\ Regime\ 2}$ were estimated as 9.39 and 9.89 for LSTAR2DL model and estimated as 8.42 and 14.75 for LSTARDL model, which suggest rejecting the null hypothesis of no cointegration. $F_{ecm,\ overall}$ statics are 9.32 and 29.97 for LSTAR2DL-ECM and LSTARDL-ECM models. Thus, it can be accepted that the error correction mechanism towards long-run equilibrium exists for both models since they are above the upper bound critical value. $F_{ecm,\ Regime\ 1}$ and $F_{ecm,\ Regime\ 2}$ statics used for testing the null hypothesis of no error correction for the corresponding regimes are above the upper bound critical value (5.20), so we can reject the null hypothesis for both regimes. The threshold parameters were estimated as −0.15 and + 0.15 for LSTAR2DL model and −0.131 and + 0.131 for LSTAR2DL-ECM

Table 4
Canada, LSTAR(2)DL and LSTAR(2)DL-ECM models.

Models:	LSTAR2DL		LSTAR2DL-ECM		LSTARDL		LSTARDL-ECM	
	Regime 1	Regime 2	Regime 1	Regime 2	Regime 1	Regime 2	Regime 1	Regime 2
Long-run Coefficients								
ly_{t-1}	0.71***(3.11)	0.84***(2.99)			0.57***(2.61)	0.31**(2.38)		
$lcop_{t-1}$	0.26*** (2.65)	0.14***(3.63)			0.29***(2.8)	0.077**(2.5)		
$lslv_{t-1}$	0.24*** (2.8)	0.134*** (2.76)			0.12** (1.81)	0.25** (2.3)		
$lgold_{t-1}$	1.8*** (3.3)	0.81*** (3.01)			1.566** (2.21)	0.81** (2.5)		
L.R.E.:Cop	2.73	6.00			1.96	4.02		
L.R.E.:slv	2.95	6.26			4.75	1.24		
L.R.E.:gold	0.39	1.03			0.36	0.38		
Error Correction Terms:								
ecm_{t-1}			−0.44**** (2.9)	−0.27*** (−2.6)			−0.47*** (−2.8)	−0.45*** (−3.7)
Short-run Coefficients								
dly_{t-1}	0.57** (1.91)	−0.22** (−2.009)	1.68*** (2.77)	0.33** (2.31)	0.662*** (2.51)	0.22*** (3.3)	0.119*** (3.051)	0.25** (2.14)
$dlcop_{t-1}$	0.85*** (2.88)	0.52** (−2.33)	0.952** (2.33)	0.901*** (2.61)	0.71** (1.88)	0.881*** (5.2)	0.981** (2.23)	0.99*** (3.01)
$dlslv_{t-1}$	0.97** (2.6)	0.744** (2.28)	2.115*** (2.95)	0.536** (2.15)	0.917** (2.04)	0.58** (2.8)	0.994*** (3.41)	0.45*** (2.45)
$dlgold_{t-1}$	0.99*** (4.2)	0.68*** (3.4)	1.141*** (4.22)	0.118*** (3.31)	0.75*** (6.7)	0.31*** (2.7)	0.42*** (2.62)	−0.35*** (−2.7)
cons	0.13*** (3.13)	0.003** (2.22)	0.009** (2.5)	−0.098 (0.01)	0.0099** (2.66)	−0.28** (1.89)	0.002* (1.330)	0.88** (2.29)
γ	−9.63*** (−3.9)		−9.118** (−2.15)		−9.88** (−2.2)		−10.12*** (−2.99)	
c	−0.131***, +0.131*** (−33, +3.3)		−0.114***, +0.114*** (-3.27, +3.27)		−0.197*** (−2.82)		−0.23** (−1.9)	
s_t	dly_{t-1}		dly_{t-1}		$dlgold_{t-1}$		$dlgold_{t-1}$	

Goodness of fit and diagnostics tests:	LSTAR2DL	LSTAR2DL-ECM	LSTARDL	LSTARDL-ECM
R^2	0.68	0.71	0.76	0.69
Adj. R^2	0.64	0.68	0.67	0.64
Q(1–2)	0.2[0.91]	0.13[0.94]	0.4[0.81]	0.4[0.50]
ARCH(1–2)	2.3[0.20]	2.16[0.18]	2.6[0.18]	2.7[0.12]
F (STAR)	0.24	0.29	0.12	0.23
Regime specific, Overall (joint tests in both regimes) Error Correction Tests:				
	$F_{PSS,\ Regime\ 1} = 42.31[0.00]$	$F_{ecm,\ Regime\ 1(1,178)} = 46.92[0.00]$	$F_{PSS,\ Regime\ 1} = 32.94[0.000]$	$F_{ECMTERM,\ Regime\ 1}$:33.91 [0.000]
	$F_{PSS,\ Regime\ 2} = 37.34[0.00]$	$F_{ecm,\ Regime\ 2(1,178)} = 32.99[0.00]$	$F_{PSS,\ Regime\ 2} = 38.76[0.000]$	$F_{ECM\ TERM,\ Regime\ 2}$:41.87 [0.000]
	$F_{PSS,\ overall} = 49.45[0.00]$	$F_{ecm,\ overall\ (2,178)} = 48.39[0.00]$	$F_{PSS,\ overall} = 41.94[0.000]$	$F_{ECM,\ OVERALL}$:49.48[0.000]

model. The transition speed is −7.47 for LSTAR2DL model and −7.30 for LSTAR2DL-ECM model, indicating a smooth transition from one regime to another. The first lag of economic growth rate (*dly_{t-1}*) was determined as the optimum transition variable for both models. Hence, when the growth rate is smaller than −0.15 or bigger than 0.15, the second-order logistic function approaches 1 and the outer regimes (regime 2) become dominant. In other case, the inner regime (regime 1) becomes dominant. Long run elasticity was calculated as 1.21 for gold production growth in regime 2, which means that once *dly_{t-1}* exceeds the threshold values, 1% increase in gold production gives rise to 1.21% increase in economic growth. It was calculated as 2.22 for regime 1, which means the same amount increase in gold production induces 2.22% increase in economic growth. The elasticity of copper production growth is 3.83 for regime 1, which means that a 1% increase in copper growth gives rise to 3.83% increase in economic growth. The elasticity reduces to 0.50 in regime 2, so we can say the effect of copper production on economic growth is very low when compared with regime 1. As regards LSTAR2DL-ECM model, the coefficients of the *ecm_{t-1}* terms were estimated as −0.37 and −0.55 for regime 1 and regime 2, respectively, showing that there is an error correcting mechanism in the system. If we evaluate the short-run dynamics in LSTAR2DL model, a 1% increase in copper production brings about 0.99% increase in economic growth in regime 1 and 0.77% one in regime 2. The effect of a 1% increase in gold production on GDP was estimated as 0.36% for regime 1 and 0.59% for regime 2.

For LSTARDL and LSTARDL-ECM models, thresholds parameters were estimated as −0.193 and −0.211. The transition variables were estimated as *dly_{t-1}* for both models. Accordingly, when the first lag of economic growth rate exceeds −0.193 in LSTARDL model, transition function approaches to 1 and the economy shifts to regime 2. In other case (*$dly_{t-1} < -0.193$*), the function approaches to 0 and regime 1 prevails. The transition speeds are smooth as in LSTAR2DL models. The long-run elasticities of copper production were calculated as 1.81 in regime 1 and 29.04 in regime 2, meaning a 1% percent increase in copper production gives rise to 1.81% increase in economic growth in regime 1 and 29.04% increase in regime 2. The effect of copper production in regime 2 is very huge. The long-run elasticities of gold production were calculated as 0.92 and 2.25 for regime 1 and regime 2, respectively. So, the long run effect of gold production on economic growth is higher in regime 2. In LSTARDL-ECM model, the coefficients of *ecm_{t-1}* terms were estimated as −0.39 in regime 1 and -0.47 in regime 2, indicating that 39% of the deviations from long-run are corrected in regime 1 and 44% of them are corrected in regime 2 in one period. As to short-run dynamics in LSTARDL model, a 1% increase in copper production brings about 0.51% increase in economic growth in regime 1 and 0.21% increase in regime 2. The same amount increase in gold production gives rise to a 0.51% increase in economic growth in regime 1 and a 0.12% increase in regime 2. If we evaluate the long run and short-run effects of the precious metals under estimation on the

Table 5
Mexico, LSTAR(2)DL and LSTAR(2)DL-ECM models.

Models:	LSTAR2DL		LSTAR2DL-ECM		LSTARDL		LSTARDL-ECM	
	Regime 1	Regime 2	Regime 1	Regime 2	Regime 1	Regime 2	Regime 1	Regime 2
Long-run Coefficients								
ly_{t-1}	0.76*** (3.9)	0.288*** (2.64)			−0.581*** (−2.91)	0.55** (1.9)		
$lcop_{t-1}$	0.13** (1.85)	−0.132*** (−6.5)			0.291*** (2.88)	−0.58*** (−2.9)		
$lslv_{t-1}$	0.06** (2.41)	0.57*** (3.99)			0.45*** (3.99)	0.39*** (4.4)		
$lgold_{t-1}$	0.92*** (5.41)	0.29** (1.97)			0.389*** (3.299)	0.47** (1.99)		
L.R.E.:cop	5.84	−2.18			−1.99	−0.94		
L.R.E.:slv	12.66	0.50			−1.29	1.41		
L.R.E.:gold	0.82	0.99			−1.49	1.17		
Error Correction Terms:								
ecm_{t-1}			−0.287*** (4.14)	−0.233*** (−3.39)			−0.311*** (−4.51)	−0.293*** (−3.66)
Short-run Coefficients								
dly_{t-1}	0.34** (2.14)	−0.822*** (−2.6)	−0.68** (−2.33)	1.31** (2.15)	0.45*** (2.51)	0.51** (2.26)	0.119*** (3.51)	0.238** (2.40)
$dlcop_{t-1}$	0.35*** (2.9)	−0.26** (−2.3)	0.88*** (2.44)	−1.11** (−2.36)	−0.72** (−1.98)	0.83*** (5.18)	−0.281** (−2.23)	0.88*** (3.55)
$dlslv_{t-1}$	0.23*** (2.64)	0.0754*** (3.2)	0.411*** (3.51)	−0.356** (−2.15)	0.27** (2.17)	−0.253*** (−2.88)	0.554*** (3.78)	−0.45*** (3.3)
$dlgold_{t-1}$	0.445*** (4.3)	−0.45*** (−3.8)	1.466** (1.95)	−0.308*** (−3.73)	0.25*** (5.17)	0.83*** (2.44)	0.42*** (2.67)	−0.35*** (−2.74)
cons	0.0013** (2.3)	−0.112*** (−2.9)	0.0007*** (2.52)	−0012** (2.33)	0.0986** (2.16)	−0.182** (−2.33)	−0.012 **(2.26)	−0.023** (1.97)
γ	−6.344*** (−4.3)		−7.116*** (−2.51)		−7.18** (−2.19)		−7.195** (−1.98)	
c	−0.09***, +0.09*** (−6.5, +6.5)		−0.07***, +0.07*** (−4.74, +4.74)		−0.099*** (−2.78)		−0.099*** (−2.78)	
s_t	dly_{t-1}		dly_{t-1}		dly_{t-1}		dly_{t-1}	

Goodness of fit and diagnostics tests:	LSTAR2DL	LSTAR2DL-ECM	LSTARDL	LSTARDL-ECM
R^2	0.67	0.68	0.67	0.69
Adj. R^2	0.64	0.66	0.63	0.67
Q(1–2)	0.2[0.81]	0.19[0.91]	0.33[0.84]	0.46[0.50]
ARCH(1–2)	2.1[0.18]	2.15[0.21]	2.55[0.15]	2.81[0.17]
F (STAR)	0.18	0.18	0.09	0.15
Regime specific, Overall (joint tests in both regimes) Error Correction Tests:				
	$F_{PSS,\ Regime\ 1} = 9.6329$ [0.09]	$F_{ecm,\ Regime1\ (1,178} = 6.88$[0.09]	$F_{PSS,\ Regime\ 1} = 10.42$[0.0]	$F_{ECM\_TERM,\ Regime\ 1}$:8.80[0.09]
	$F_{PSS,\ Regime\ 2} = 8.812$ [0.09]	$F_{ecm,\ Regime\ 2\ (1,178)=}$ 7.19[0.09]	$F_{PSS,\ Regime\ 2} = 11.55$[0.0]	$F_{ECM\_TERM,\ Regime\ 2}$:8.65[0.09]
	$F_{PSS,\ overall} = 9.241$[0.00]	$F_{ecm,\ overall\ (2,178}) = 6.28$[0.09]	$F_{PSS,\ overall} = 8.826$[0.0]	$F_{ECM,\ OVERALL}$:8.42[0.09]

economic growth of the Philippines as a whole, we can say that the effect is positive in both periods and regimes but differs according to the regimes of the economy, indicating an asymmetry in the models.

The analysis results for South Africa can be found in Table 6. According to R^2 values, the explanatory power of LSTAR2DL model is higher than one of LSTARDL model. STARDL-type cointegration test for the whole model was tested with $F_{PSS,\ overall}$ bound test static, and it was estimated as 9.71 for LSTAR2DL model and 12.50 for LSTARDL model. The values are over the upper bound critical value (5.81) at a 1% significance level, meaning that rejecting the null hypothesis suggesting no cointegration. $F_{PSS,\ Regime\ 1}$ and $F_{PSS,\ Regime\ 2}$, the test statics used for testing regime specific cointegration were estimated as 9.39 and 9.90 for LSTAR2DL model and 8.50 and 14.80 for LSTARDL model. These results also suggest rejecting null hypothesis representing no cointegration since they are over the upper bound critical value at 1% significance level. For LSTAR2DL-ECM and LSTARDL-ECM models, $F_{ecm,\ overall}$ statics were estimated as 9.50 and 29.99, respectively. Thus, we can reject the null hypothesis of no error correction mechanism towards long-run at 1% significance level for the whole model. $F_{ecm,\ Regime\ 1}$ and $F_{ecm,\ Regime\ 2}$ statics used for deciding if regime specific error correction mechanism exists are 7.97 and 10.80 for LSTAR2DL-ECM model and 28.17 and 31.80 for LSTARDL-ECM model, which leads to rejection of the null hypothesis of no error correction mechanism in the models.

The threshold parameters were estimated as −0.141 and + 0.141 for LSTAR2DL model and −0.114 and + 0.114 for LSTAR2DL-ECM model. The transition speed is −6.95 for LSTAR2DL model and −7.12 for LSTAR2DL-ECM model, showing a smooth transition between regimes. The first lag of economic growth (dly_{t-1}) was determined as the optimum transition variable for both models. Thus, if the growth rate is smaller than −0.141 or bigger than +0.141 in LSTAR2DL model, the second-order logistic function approaches 1 and regime 2 becomes dominant. For the other case ($-0.141 < dly_{t-1} < +0.141$), regime 1 becomes dominant. In the same model, the long run elasticities (*lre)* were calculated as 2.51 in regime 1 and 1.41 in regime 2 for copper production, meaning a 1% increase in copper production gives rise to 2.51% increase in economic growth in regime 1 and 1.41% increase in regime 2.

As for the gold production, the elasticities are 0.73 and 1.32 for regime 1 and regime 2, indicating the effect of gold production is higher in regime 2. In LSTARDL model, long-run elasticities are 1.6 in regime 1 and 7.79 in regime 2 for copper production and 0.64 and 1.39 in corresponding regimes for gold production. So, the effect of the precious

Table 6
Peru, LSTAR(2)DL and LSTAR(2)DL-ECM models.

Models:	LSTAR2DL		LSTAR2DL-ECM		LSTARDL		LSTARDL-ECM	
	Regime 1	Regime 2	Regime 1	Regime 2	Regime 1	Regime 2	Regime 1	Regime 2
Long-run Coefficients								
ly_{t-1}	0.14*** (3.91)	0.29*** (2.89)			0.49*** (3.11)	0.41*** (2.54)		
$lcop_{t-1}$	0.74*** (2.93)	0.15*** (3.82)			0.39** (1.84)	0.43** (2.03)		
$lslv_{t-1}$	0.81*** (4.21)	0.94*** (2.91)			0.21*** (4.6)	0.41*** (8.17)		
$lgold_{t-1}$	0.65*** (3.13)	0.97*** (2.81)			0.086*** (2.66)	0.40*** (3.07)		
L.R.E.:cop	0.19	1.93			1.25	0.95		
L.R.E.:slv	0.17	0.30			2.33	1.00		
L.R.E.:gold	0.21	0.29			5.59	1.02		
Error Correction Terms:								
ecm_{t-1}			−0.28** (2.16)	−0.32*** (2.92)			−0.43*** (3.63)	−0.29*** (3.72)
Short-run Coefficients								
dly_{t-1}	0.71** (2.18)	0.31*** (2.8)	0.21*** (3.57)	0.34*** (2.77)	0.39*** (3.74)	0.54*** (2.76)	0.32*** (2.99	0.18*** (2.5)
$dlcop_{t-1}$	0.64** (2.30)	0.16*** (3.26)	0.17** (2.32)	0.28*** (2.95)	0.34*** (3.34)	0.563*** (2.94)	0.14** (2.2)	0.193** (2.02)
$dlslv_{t-1}$	0.15*** (3.61)	0.15** (2.32)	0.71*** (2.7)	0.46*** (3.07)	0.33*** (2.98)	0.59*** (2.98)	0.22** (2.08)	0.162*** (2.64)
$dlgold_{t-1}$	0.54*** (3.21)	0.47*** (2.6)	0.32*** (2.56)	0.48*** (2.93)	0.28*** (3.81)	0.63*** (3.03)	0.78*** (2.87)	0.572*** (2.97)
cons	0.011*** (2.89)	1.27*** (7.91)	0.53** (1.98)	0.97** (2.11)	0.94*** (2.76)	0.08** (2.33)	0.21** (2.16)	0.21** (2.17)
γ	−8.03** (1.97)		−8.16*** (2.56)		−7.921*** (3.17)		−8.22** (1.99)	
c	−0.77***, +0.77*** (−5.41,+5.41)		−0.16***, +0.16*** (−2.99,+2.99)		0.11*** (2.54)		0.125*** (2.49)	
s_t	dly_{t-1}		dly_{t-1}		dly_{t-1}		dly_{t-1}	
Goodness of fit and diagnostics tests:								
	LSTAR2DL		LSTAR2DL-ECM		LSTARDL		LSTARDL-ECM	
R^2	0.77		0.73		0.72		0.73	
Adj. R^2	0.69		0.68		0.72		0.71	
Q(1–2)	0.2[0.71]		0.2[0.66]		0.27[0.71]		0.4[0.69]	
ARCH(1–2)	2.2[0.25]		2.85[0.21]		2.6[0.18]		2.45[0.28]	
F (STAR)	0.11		0.16		0.25		0.27	
Regime specific, Overall (joint tests in both regimes) Error Correction Tests:								
	$F_{PSS,\ Regime\ 1}$ = 9.93 $F_{PSS,\ Regime\ 2}$ = 6.3086 $F_{PSS,\ overall}$ = 8.25		$F_{ecm,\ Regime1\ (1,178}$ = 7.2376 $F_{ecm,\ Regime\ 2\ (1,178)=}$ 8.4059 $F_{\ ecm,\ overall\ (2,178}$) = 7.8557		$F_{PSS,\ Regime\ 1}$ = 10.9879 $F_{PSS,\ Regime\ 2}$ = 9.153875 $F_{PSS,\ overall}$ = 9.36094		$F_{ECM\_TERM,\ Regime\ 1}$:6.2662 $F_{ECM\_TERM,\ Regime\ 2}$:8.1795 $F_{ECM,\ OVERALL}$:6.9365	

Table 7
Philippines, LSTAR(2)DL and LSTAR(2)DL-ECM models.

Models:	LSTAR2DL		LSTAR2DL-ECM		LSTARDL		LSTARDL-ECM	
	Regime 1	Regime 2	Regime 1	Regime 2	Regime 1	Regime 2	Regime 1	Regime 2
Long-run Coefficients								
ly_{t-1}	0.69*** (4.23)	0.351*** (2.69)			0.69*** (2.89)	0.61*** (3.41)		
$lcop_{t-1}$	0.18*** (2.45)	0.69*** (2.68)			0.38*** (2.65)	0.021*** (3.89)		
$lgold_{t-1}$	0.31** (2.31)	0.29*** (4.07)			0.75*** (3.28)	0.27*** (4.36)		
L.R.E.:cop	3.83	0.50			1.81	29.04		
L.R.E.:gold	2.22	1.21			0.92	2.25		
Error Correction Terms:								
ecm_{t-1}			−0.37***(2.89)	−0.55***(-3.31)			−0.39***(-5.61)	−0.47***(-5.23)
Short-run Coefficients								
dly_{t-1}	0.29** (1.88)	0.281*** (3.64)	0.87*** (2.97)	0.44** (2.2)	0.219** (2.21)	0.79*** (4.29)	0.347*** (3.2)	0.38** (2.09)
$dlcop_{t-1}$	0.99*** (3.25)	0.77** (2.39)	0.27** (2.28)	0.37** (2.21)	0.512** (1.99)	0.21*** (5.2)	0.48***(2.90)	0.471*** (2.73)
$dlgold_{t-1}$	0.367** (2.32)	0.59*** (2.98)	0.75** (2.37)	0.59** (2.129)	0.512** (2.23)	0.123*** (3.17)	0.33*** (2.97)	0.488*** (2.99)
Cons	0.29*** (3.35)	0.19** (2.29)	0.5*** (2.97)	−0.13** (2.12)	0.232** (2.39)	−0.07*** (2.7)	0.001** (1.91)	0.151** (2.27)
γ	−7.474*** (−2.89)		−7.3***(-3.51)		−7.91***(-2.91)		−8.19**(-2.12)	
C	−0.15***,+0.15*** (−2.61; +2.61)		−0.131***,+0.131*** (−3.5, +3,5)		−0.193** (−2.87)		−0.211** (−1.99)	
s_t	dly_{t-1}		dly_{t-1}		dly_{t-1}		dly_{t-1}	
Goodness of fit and diagnostics tests:								
R^2	0.74		0.72		0.638		0.79	
Adj. R^2	0.70		0.68		0.60		0.72	
Q(1–2)	0.2[0.91]		0.13[0.94]		0.23[0.83]		0.41[0.51]	
ARCH(1–2)	2.31[0.11]		2.9[0.19]		2.86 [0.14]		2.69[0.16]	
F (STAR)	0.09		0.17		0.32		0.29	
Regime specific, Overall (joint tests in both regimes) Error Correction Tests:								
	$F_{PSS,\ Regime\ 1}$ = 9.397[0.00] $F_{PSS,\ Regime\ 2}$ = 9.89[0.00] $F_{PSS,\ overall}$ = 9.70[0.00]		$F_{ecm,\ Regime\ 1}$ = 7.95[0.00] $F_{ecm,\ Regime\ 2)=}$ 10.76[0.00] $F_{\ ecm,\ overall}$ = 9.32 [0.00]		$F_{PSS,\ Regime\ 1}$ = 8.42 [0.00] $F_{PSS,\ Regime\ 2}$ = 14.75[0.00] $F_{PSS,\ overall}$ = 12.11 [0.00]		$F_{ECM\_TERM,\ Regime\ 1}$: 28.17[0.00] $F_{ECM\_TERM,\ Regime\ 2}$: 31.76[0.00] $F_{ECM,\ OVERALL}$: 29.97[0.00]	

Table 8

South Africa, LSTAR(2)DL and LSTAR(2)DL-ECM models.

Models:	LSTAR2DL		LSTAR2DL-ECM		LSTARDL		LSTARDL-ECM	
	Regime 1	vRegime 2	Regime 1	Regime 2	Regime 1	Regime 2	Regime 1	Regime 2
Long-run Coefficients								
ly_{t-1}	0.88*** (4.27)	0.41** (2.77)			0.72*** (2.82)	0.53*** (3.85)		
$lcop_{t-1}$	0.35** (2.36)	0.29** (2.46)			0.45** (2.65)	0.068*** (3.29)		
$lgold_{t-1}$	1.2** (2.21)	0.31* (1.99)			1.11*** (3.23)	0.38*** (4.31)		
L.R.E.:cop	2.51	1.41			1.6	7.79		
L.R.E.:gold	0.73	1.32			0.64	1.39		
Error Correction Terms:								
ecm_{t-1}			−0.31*** (2.8)	−0.33*** (−3.29)			−0.29*** (−5.327)	−0.33*** (−5.64)
Short-run Coefficients								
dly_{t-1}	0.93* (1.82)	0.32*** (−2.91)	1.55*** (2.96)	0.87** (2.12)	0.66** (2.19)	0.87*** (4.16)	0.39*** (3.15)	0.34** (2.05)
$dlcop_{t-1}$	0.59** (2.32)	0.51** (−2.29)	0.57** (2.16)	0.40** (2.11)	0.33* (1.99)	0.87*** (5.18)	0.45*** (2.95)	0.44*** (2.99)
$dlgold_{t-1}$	0.63*** (3.31)	0.74*** (3.62)	1.09** (2.32)	0.60** (2.11)	0.61** (2.13)	0.88*** (2.99)	0.67*** (2.89)	0.48** (2.27)
cons	0.26*** (3.23)	0.002** (2.22)	0.65*** (2.95)	−0.65** (2.14)	0.11** (2.33)	−0.36** (2.63)	0.09* (1.89)	0.65** (2.19)
γ	−6.95** (−2.19)		−7.12*** (−3.54)		−8.38*** (−2.72)		−7.76** (−2.11)	
C	−0.141** + 0.141** (−2.56, +2.56)		−0.114***,+0.114*** (−3.3, +3.3)		−0.25*** (−2.85)		−0.29* (−1.97)	
s_t	dly_{t-1}		dly_{t-1}		dly_{t-1}		dly_{t-1}	
Goodness of fit and diagnostics tests:								
R^2	0.72		0.69		0.68		0.71	
Adj. R^2	0.69		0.63		0.63		0.66	
Q(1–2)	0.2[0.91]		0.1[0.94]		0.4[0.81]		0.4[0.50]	
ARCH(1–2)	2.1[0.19]		2.16[0.24]		2.6[0.18]		2.7[0.15]	
F (STAR)	0.19		0.16		0.22		0.11	
Regime specific, Overall (joint tests in both regimes) Error Correction Tests:								
	$F_{\text{PSS, Regime 1}} = 9.395[0.00]$ $F_{\text{PSS, Regime 2}} = 9.90[0.00]$ $F_{\text{PSS, overall}} = 9.71[0.00]$		$F_{\text{ecm, Regime 1(1,178)}} = 7.97[0.00]$ $F_{\text{ecm, Regime (1,178)}} = 10.8[0.00]$ $F_{\text{ecm, overall (2,178)}} = 9.5[0.00]$		$F_{\text{PSS, Regime 1}} = 8.5[0.000]$ $F_{\text{PSS, Regime 2}} = 14.8[0.000]$ $F_{\text{PSS, overall}} = 12.50[0.000]$		$F_{\text{ECMTERM, Regime 1}}$:28.17[0.000] $F_{\text{ECM TERM, Regime 2}}$:31.8[0.000] $F_{\text{ECM, OVERALL}}$:29.99[0.000]	

Table 9

The USA, LSTAR(2)DL and LSTAR(2)DL-ECM models.

Models:	LSTAR2DL		LSTAR2DL-ECM		LSTARDL		LSTARDL-ECM	
	Regime 1	Regime 2	Regime 1	Regime 2	Regime 1	Regime 2	Regime 1	Regime 2
Long-run Coefficients								
ly_{t-1}	0.61*** (2.49)	0.52*** (2.81)			0.63*** (2.53)	0.39**** (2.83)		
$lcop_{t-1}$	0.53*** (2.68)	0.45*** (2.86)			0.49** (2.73)	0.628** (2.37)		
$lgold_{t-1}$	0.92** (2.417)	0.58** (1.88)			1.33** (2.66)	0.59** (2.43)		
L.R.E.:cop	1.15	1.15			1.28	0.62		
l.R.E.gold	0.66	0.89			0.47	0.66		
Error Correction Terms:								
ecm_{t-1}			−0.29*** (2.83)	−0.37*** (−2.49)			−0.31*** (−2.87)	−0.33*** (−2.89)
Short-run Coefficients								
dly_{t-1}	0.66** (1.92)	0.27** (−2.24)	0.65*** (2.63)	0.27** (2.12)	0.59*** (2.85)	0.272*** (3.23)	0.49*** (3.41)	0.42*** (2.53)
$dlcop_{t-1}$	0.68** (2.21)	0.23*** (2.95)	0.55*** (2.67)	0.411** (2.22)	0.46** (2.41)	0.409*** (5.81)	0.522*** (2.96)	0.552** (2.24)
$dlgold_{t-1}$	0.52*** (3.88)	0.44*** (3.309)	0.78** (2.14)	0.423*** (2.54)	0.609** (2.13)	0.494** (2.401)	0.56*** (2.92)	0.27*** (2.71)
cons	0.25*** (5.32)	0.145** (2.21)	0.232*** (2.54)	0.051** (2.36)	0.271** (2.44)	0.078*** (2.61)	1.08 (1.11)	0.59*** (2.91)
γ	−6.8** (−2.33)		−7.02***(-4.12)		−6.76** (−2.26)		−7.69** (−2.33)	
C	−0.16*** + 0.16*** (−2.64, +2.64)		−0.125***, +0.125*** (−2.89, +2.98)		−0.241** (−2.23)		−0.241** (−1.79)	
s_t	$dlgold_{t-1}$		$dlgold_{t-1}$		$dlgold_{t-1}$		$dlgold_{t-1}$	
Goodness of fit and diagnostics tests:								
R^2	0.61		0.66		0.58		0.71	
Adj. R^2	0.59		0.64		0.54		0.68	
Q(1–2)	0.33[0.77]		0.53[0.59]		0.42[0.5]		0.39[0.70]	
ARCH(1–2)	2.69[0.16]		2.71[0.157]		2.61[0.16]		2.62[0.16]	
F (STAR)	0.10		0.12		0.08		0.17	
Regime specific, Overall (joint tests in both regimes) Error Correction Tests:								
	$F_{\text{PSS, Regime 1}} = 7.88[0.00]$ $F_{\text{PSS, Regime 2}} = 8.135[0.00]$ $F_{\text{PSS, overall}} = 8.112[0.00]$		$F_{\text{ecm, Regime 1(1,178)}} = 7.68[0.00]$ $F_{\text{ecm, Regime (1,178)}} = 6.51[0.00]$ $F_{\text{ecm, overall (2,178)}} = 7.33[0.00]$		$F_{\text{PSS, Regime 1}} = 44.36[0.000]$ $F_{\text{PSS, Regime 2}} = 48.21[0.000]$ $F_{\text{PSS, overall}} = 49.31[0.000]$		$F_{\text{ECMTERM, Regime 1}}$:7.95[0.000] $F_{\text{ECM TERM, Regime 2}}$:10.75[0.000] $F_{\text{ECM, OVERALL}}$:9.82[0.000]	

metals on economic growth is higher in regime 2. The effect of gold production on the economic growth of South Africa is less than that of copper production in both regimes. Regarding LSTAR2DL-ECM model, the coefficients of the ecm_{t-1} terms were estimated as −0.31 and −0.33 for regime 1 and regime 2, respectively, meaning 31% of the deviations from long run are corrected in one period in regime 1 and 33% of them are corrected in one period in the other regime. As for short-run dynamics in LSTAR2DL model, a 1% increase in copper production brings about 0.59% increase in economic growth in regime 1 and the effect is 0.51% in the other regime. The same amount increase in gold production induces 0.63% increase in regime 1 and 0.74% increase in regime 2. In LSTAR2DL-ECM model, the short-run effects of the precious metals on economic growth are positive in both regimes.

For LSTARDL and LSTARDL-ECM models, transition variables were estimated as the first lag of the economic growth (dly_{t-1}) and thresholds parameters were estimated as −0.25 and −0.29, respectively. Hence, when the first lag of economic growth rate exceeds −0.25 in LSTARDL model, transition function approaches to 1 and the economy moves to regime 2. In other case ($dly_{t-1}<-0.25$), the function approaches to zero and regime 1 prevails. The transition speeds (−8.38 and −7.76) are smooth the models. In LSTARDL-ECM model, the coefficients of ecm_{t-1} terms were estimated as −0.29 in regime 1 and -0.33 in regime 2, meaning that 29% of the deviations from the long run are corrected in regime 1 and 33% of them are corrected in regime 2 in one period. Regarding the short-run dynamics in LSTARDL model, a 1% increase in copper production brings about a 0.33% increase in economic growth while the same amount increase in gold production does a 0.61% increase in regime 1. The effect of both precious metals in regime 2 is very close to each other by 0.87% and 0.88%. In brief, gold and copper productions have a positive effect on South Africa's economic growth in the long and short run. The effect differs according to the regime the economy being in, indicating an asymmetry in the model.

The analysis results for Canada are presented in Table 7. According to R^2 values, LSTARDL is the best model describing Canada's economy. $F_{PSS,\ overall}$ bound test static was estimated as 49.45 for LSTAR2DL model and 41.94 for LSTARDL model. The values are over the upper bound critical value (4.94) at a 1% significance level, meaning that rejecting the null hypothesis suggesting no STARDL-type cointegration. $F_{PSS,\ Regime\ 1}$ and $F_{PSS,\ Regime\ 2}$ were estimated as 42.31 and 37.34 for LSTAR2DL model and 32.94 and 38.76 for LSTARDL model, which supports the rejection of the null hypothesis suggesting no cointegration since they are bigger than the upper bound critical value at 1% significance level. For LSTAR2DL-ECM and LSTARDL-ECM, $F_{ecm,\ overall}$ statics were estimated as 48.39 and 49.48, respectively. Thus, we can reject the null hypothesis suggesting no error correction mechanism towards long-run at 1% significance level for the whole model. $F_{ecm,\ Regime\ 1}$ and $F_{ecm,\ Regime\ 2}$ statics are 46.92 and 32.99 for LSTAR2DL-ECM model and 33.91 and 41.87 for LSTARDL-ECM model, which results in rejection of the null hypothesis of no error correction mechanism in the models.

The threshold parameters were estimated as −0.131 and + 0.131 for LSTAR2DL model and −0.114 and + 0.114 for LSTAR2DL-ECM model. The transition speeds are very close to each other, they are calculated as −9.63 for LSTAR2DL model and −9.11 for LSTAR2DL-ECM model, showing that transition from one regime to another is smooth. The first lag of economic growth (dly_{t-1}) was determined as the optimum transition variable for both models. Accordingly, when the growth rate is smaller than −0.131 or bigger than +0.131 in LSTAR2DL model, the second-order logistic function approaches 1 and the outer regimes (regime 2) become dominant. If the transition variable between two threshold parameters ($-0.131 < dly_{t-1} < +0.131$), regime 1 becomes dominant. In the same model, the long run elasticities (*lre)* were calculated as 2.73 in regime 1 and 6.00 in regime 2 for copper production, meaning a 1% increase in copper production gives rise to 2.73% increase in economic growth in regime 1 and 6% increase in regime 2. This result shows copper production has more effect on the economic growth of Canada in regime 2. As for the gold production, the elasticities are 0.39 and 1.03 for regime 1 and regime 2, indicating the effect of gold production is also higher in regime 2. According to calculated *lre* for silver production, 1% increase in silver production leads to a 2.95% increase in economic growth in regime 1 and 6.26% increase in regime 2. The *lre* in LSTARDL model shows that a 1% increase in copper production brings about 1.96% increase in economic growth in regime 1 and 4.02% increase in regime 2. The effect of the same amount increase in silver production is 4.75% in regime 1 and 1.24% in regime 2. Lastly, according to long-run elasticities for gold production, a 1% increase in gold production leads to 0.36% and 0.38% in regime 1 and regime 2, respectively.

In LSTAR2DL-ECM model, the coefficients of the ecm_{t-1} terms were estimated as −0.44 and −0.27 for regime 1 and regime 2, respectively, indicating an error correcting mechanism in the system. Accordingly, 44% of the deviations from the long run are corrected in regime 1 and 27% percent of them are corrected in regime 2 in one period. Regarding short-run dynamics in LSTAR2DL model, a 1% increase in copper production brings about a 0.85% increase in economic growth in regime 1 and 0.52% one in regime 2. The effect of a 1% increase in silver production was estimated as 0.97% for regime 1 and 0.74% for regime 2. The same amount increase in gold production induces 0.99% increase in economic growth in regime 1 and 0.68% one in regime 2. In LSTAR2DL-ECM model structure, the short-run effects of the precious metals on economic growth are positive in both regimes.

For LSTARDL and LSTARDL-ECM models, thresholds parameters were estimated as −0.197 and −0.23, respectively. The transition variables were estimated as the first lag of the gold production growth rate ($dlgold_{t-1}$). If the first lag of gold production growth rate exceeds −0.197, transition function approaches to 1 and the economy moves to regime 2. In other case ($dlgold_{t-1}<-0.197$), the function approaches to 0 and regime 1 prevails. The transition speeds are smooth in both models. As regards short-run dynamics in the model, a 1% increase in copper production leads to a 0.71% increase in economic growth in regime 1 and 0.88% increase in regime 2. For silver production, we can say a 1% increase in the production gives rise to a 0.91% increase in the economic growth of Canada in regime 1 and 0.58% one in regime 2. For gold production, the effect is higher in regime 1 (0.75%) than regime 2 (0.31%). In LSTARDL-ECM model, the coefficients of ecm_{t-1} terms were estimated as −0.47 in regime 1 and -0.45 in regime 2, indicating that 47% of the deviations from the long-run are corrected in regime 1 and 45% of them are corrected in regime 2 in one period. If we summarize, according to LSTARDL model, the best model describing well economy of Canada, all precious metals production has a positive effect on economic growth in the long and short run. The effect is not the same in all regimes, leading to the acceptation of asymmetry in the model. In the long run, gold production has the lowest effect on the economy. In the short run, gold and silver production have more effect in regime 1 while copper production has more effect on regime 2.

The test results for Mexico are presented in Table 8. R^2 values of LSTAR2DL and LSTARDL models are the same, so the two models are well describing the economy of Mexico. Estimated $F_{PSS,\ overall}$ statics are 9.24 and 8.82 for LSTAR2DL and LSTARDL model, respectively. As they are higher than the upper bound critical value (4.94) at 1% level, the null hypothesis of no cointegration can be clearly rejected for each model. As for individual regimes, $F_{PSS,\ Regime\ 1}$ and $F_{PSS,\ Regime\ 2}$ were estimated as 9.63 and 8.81 for LSTAR2DL model and estimated as 10.42 and 11.55 for LSTARDL model, which suggest rejecting the null hypothesis of no cointegration. $F_{ecm,\ overall}$ statics are 6.28 and 8.42 for LSTAR2DL-ECM and LSTARDL-ECM models. Thus, it can be accepted that the error correction mechanism towards long-run equilibrium exists for both models since they are above the upper bound critical value. $F_{ecm,\ Regime\ 1}$ and $F_{ecm,\ Regime\ 2}$ statics used for testing the null hypothesis of no error correction for the corresponding regimes are above the upper bound critical value (4.94), so we can reject the null hypothesis for both regimes. The threshold parameters were estimated as −0.09 and + 0.09 for LSTAR2DL model and −0.07 and + 0.07 for LSTAR2DL-ECM model.

The transition speed is −6.34 for LSTAR2DL model and −7.11 for LSTAR2DL-ECM model, indicating a smooth transition from one regime to another. The first lag of economic growth rate (dly_{t-1}) was determined as the optimum transition variable for both models. Hence, when the growth rate is smaller than −0.09 or bigger than 0.09, the second-order logistic function approaches 1 and the outer regimes (regime 2) become dominant in LSTARDL model. In other case, the inner regime (regime 1) becomes dominant. Long run elasticity was calculated as 5.84 for copper production growth in regime 1 while it is −2.18 in regime 2, which means that once dly_{t-1} exceeds the threshold values, 1% increase in copper production gives rise to 2.18% decrease in economic growth but same amount increase in regime 1 induces 5.84% increase in economic growth. The elasticity of silver production growth is 12.66 for regime 1, which means that a 1% increase in silver production growth gives rise to 12.66% increase in economic growth. The elasticity reduces to 0.50 in regime 2, so we can say the effect of silver production on economic growth is very high when compared with regime 1. As regards LSTAR2DL-ECM model, the coefficients of the ecm_{t-1} terms were estimated as −0.28 and −0.23 for regime 1 and regime 2, respectively, showing that there is an error correcting mechanism in the system. If we evaluate the short-run dynamics in LSTAR2DL model, a 1% increase in copper production brings about a 0.35% increase in economic growth in regime 1 but it leads to a 0.26% decrease in regime 2. The effect of a 1% increase in silver production on economic growth was estimated as 0.23% for regime 1 and 0.07% for regime 2. The same amount of increase in gold production gives rise to a 0.44% increase in economic growth in regime one while it has a negative effect, a 0.45% decrease in regime 2.

For LSTARDL and LSTARDL-ECM models, thresholds parameters were estimated as −0.09. The transition variables were estimated as dly_{t-1} for both models. Accordingly, when the first lag of economic growth rate exceeds −0.09 in the models, transition function approaches to 1 and the economy shifts to regime 2. In other case ($dly_{t-1}<-0.09$), the function approaches to 0 and regime 1 prevails. The transition speeds indicate smooth transitions between regimes. The long-run elasticities of copper production are negative in regime 1 and regime 2, meaning it has a negative effect on the economic growth of Mexico in the long run. A 1% increase in copper production growth leads to a 1.99% decrease in regime 1 and 0.94% decrease in regime 2. For silver and gold production, the effect is negative in regime 1 while it is positive in regime 2. In LSTARDL-ECM model, the coefficients of ecm_{t-1} terms were estimated as −0.31 in regime 1 and -0.29 in regime 2, indicating that 31% of the deviations from the long-run are corrected in regime 1 and 29% of them are corrected in regime 2 in one period. As to short-run dynamics in LSTARDL model, a 1% increase in copper production brings about 0.72% decrease in economic growth in regime 1 and 0.83% increase in regime 2. The effect of a 1% increase in silver production induces 0.27% increase in economic growth in regime 1 and 0.25% decrease in regime 2. The same amount increase in gold production gives rise to a 0.25% increase in economic growth in regime 1 and 0.83% increase in regime 2. To sum, both LSTAR2DL and LSTARDL models are well describing Mexico's economy. If we take LSTARDL model, the long run effect of copper production on economic growth is negative in both regimes while that of silver and gold production is negative in regime 1 and positive in regime 2. In the short run, only gold production has positive effects in both regimes. Copper production has a negative effect on regime 1 while silver production does in regime 2. These result also shows the asymmetry in the models.

The test results for Peru are presented in Table 9. The R^2 value estimated for LSTAR2DL model is higher than the one of LSTARDL model, which means the former one is the best model describing Peru's economy. Regarding STARDL-type cointegration analysis, $F_{PSS,\ overall}$ statics were estimated as 8.25 and 9.36 for LSTAR2DL and LSTARDL models, respectively. These values are higher than the upper bound critical value (4.94) at 1% significance level, hence the null hypothesis suggesting no cointegration for the overall model can be rejected strongly for each model. Likewise, the cointegration test statics for individual regimes, $F_{PSS,\ Regime\ 1}$, $F_{PSS,\ Regime\ 2}$, were estimated as 9.93 and 6.30 for LSTAR2DL model and estimated as 10.98 and 9.15 for LSTARDL model, which suggest rejecting the null hypothesis of no cointegration. For the restricted counterparts of the models, namely LSTAR2DL-ECM and LSTARDL-ECM, $F_{ecm,\ overall}$ statics were estimated as 7.85 and 6.93, respectively, which means rejecting null hypothesis suggesting no error correction mechanism towards long-run at 1% significance level for the whole model. $F_{ecm,\ Regime\ 1}$ and $F_{ecm,\ Regime\ 2}$ were estimated as 7.23 and 8.40 for LSTAR2DL-ECM model and estimated as 6.26 and 8.17 for LSTARDL-ECM model. We can reject the null hypothesis suggesting no error correction mechanism for both regimes because the values are higher than critical values.

The threshold parameters were estimated as −0.77 and + 0.77 for LSTAR2DL model and −0.16 and + 0.16 for LSTAR2DL-ECM model. The transition speed is −8.03 for LSTAR2DL model and −8.16 for LSTAR2DL-ECM model, indicating that shifting from one regime to another is smooth. The first lag of the economic growth rate (dly_{t-1}) was determined as the optimum transition variable for both models. If the growth rate is smaller than −0.77 or bigger than 0.77, the second-order logistic function approaches 1 and regime 2 becomes dominant. In other case, regime 1 becomes dominant in LSTAR2DL model. Long run elasticity was calculated as 1.93 for copper production growth in regime 2, which means that once dly_{t-1} exceeds the threshold values, 1% increase in copper production gives rise to 1.93% increase in GDP. It was calculated as 0.19 for regime 1, which means the same amount increase in copper production induces 0.19% increase in GDP. The elasticity of silver production growth for regime 1 is 0.17, which means that a 1% increase in silver production growth gives rise to a 0.17% increase in GDP. In regime 2, the elasticity is 0.30, higher than the one in regime 1. For gold production, long run elasticity was estimated as 0.21 and 0.29 for regime 1 and regime 2, respectively. Hence, when dly_{t-1} exceeds the threshold values, a 1% increase in gold production results in 0.29% increase in the economic growth of Peru. Regarding LSTAR2DL-ECM model, the coefficients of the ecm_{t-1} terms were estimated as −0.28 and −0.32 for regime 1 and regime 2, indicating an error correcting mechanism in the system. As regards short-run dynamics in LSTAR2DL model, a 1% increase in copper production brings about a 0.64% increase in economic growth in regime 1 and 0.16% one in regime 2. The effect of a 1% increase in silver production is 0.15% for both regimes. The effect of the same amount increase in gold production on economic growth was estimated as 0.54% for regime 1 and 0.47% for regime 2. The short-run effects of the precious metals on economic growth are positive in LSTAR2DL-ECM model as they are in LSTAR2DL model.

For LSTARDL and LSTARDL-ECM models, thresholds parameters were estimated as 0.11 and 0.12 for regime 1 and regime 2. The transition variables were estimated as dly_{t-1}. Accordingly, when the first lag of economic growth rate exceeds 0.11 in LSTARDL model, transition function approaches to 1 and the economy shifts to regime 2. In other case ($dly_{t-1}<0.11$), the function approaches to 0 and regime 1 prevails. The transition speeds are smooth as in LSTAR2DL models. The long-run elasticities of copper production were calculated as 1.25 in regime 1 and 0.95 in regime 2, meaning a 1% percent increase in copper production gives rise to 1.25% increase in the economic growth of Peru in regime 1 and 0.95% increase in regime 2. The long-run elasticities of silver production were calculated as 2.33 and 1.00 for regime 1 and regime 2, respectively. So, the long run effect of silver production on economic growth is higher in regime 1. Gold production has the highest effect on economic growth among all precious metals. The effect of a 1% increase in it is 5.59% in regime 1 and 1.02% in regime 2. In LSTARDL-ECM model, the coefficients of ecm_{t-1} terms were estimated as −0.43 in regime 1 and -0.29 in regime 2, indicating that 43% of the deviations from the long-run are corrected in regime 1 and 29% of them are corrected in regime 2 in one period. As to short-run dynamics in LSTARDL model, a 1% increase in copper production brings about 0.34% increase in economic growth in regime 1 and 0.56% increase in regime 2. The same amount increase in silver production gives rise to a 0.33% increase in economic growth in regime 1 and 0.59% increase in regime 2. The effect of a 1% increase in gold production induces a 0.28% increase in economic growth in regime 1 and 0.63% increase in regime 2. If we evaluate the long run and short-run effects of the precious metals under estimation on the economic growth of Peru as a whole, we can say that the effect is positive in both periods and regimes, but it is higher in regime 2 in the long run and it is higher in regime 1 in the short run if we take LSTAR2DL model. These results also indicate an asymmetry in the models.

The test results for the USA are presented in Table 3. The R^2 value estimated for LSTAR2DL model is higher than the one of LSTARDL model, which means the former one is the best model describing the USA economy. Regarding STARDL-type cointegration analysis, $F_{PSS,\ overall}$ statics were estimated as 8.112 and 49.31 for LSTAR2DL and LSTARDL models, respectively. These values are higher than the upper bound critical value (5.20) at a 1% significance level, hence the null hypothesis suggesting no cointegration for the overall model can be rejected strongly for each model. Similarly, the cointegration test statics for individual regimes, $F_{PSS,\ Regime\ 1}$ and $F_{PSS,\ Regime\ 2}$, were estimated as 7.88 and 8.135 for LSTAR2DL model and estimated as 44.36 and 48.21 for LSTARDL model, which suggests rejecting the null hypothesis of no cointegration. For the restricted counterparts of the models, namely LSTAR2DL-ECM and LSTARDL-ECM, $F_{ecm,\ overall}$ statics were estimated as 7.33 and 9.82, respectively, which means rejecting null hypothesis suggesting no error correction mechanism towards long-run at 1% significance level for the whole model. $F_{ecm,\ Regime\ 1}$ and $F_{ecm,\ Regime\ 2}$ were estimated as 7.68 and 6.51 for LSTAR2DL-ECM model and estimated as 7.95 and 10.75 for LSTARDL-ECM model. We can reject the null hypothesis suggesting no error correction mechanism for both regimes because the values are higher than critical values.

The threshold parameters were estimated as −0.16 and + 0.16 for LSTAR2DL model and −0.125 and + 0.125 for LSTAR2DL-ECM model. The transition speed is −6.8 for LSTAR2DL model and −7.02 for LSTAR2DL-ECM model, indicating that shifting from one regime to another is smooth. The first lag of gold production growth rate ($dlgold_{t-1}$) was determined as the optimum transition variable for both models. Hence, when the growth rate is smaller than −0.16 or bigger than 0.16, the second-order logistic function approaches 1 and the outer regimes (regime 2) become dominant. In other case, the inner regime becomes dominant. Long run elasticity was calculated as 0.89 for gold production growth in regime 2, which means that once $dgold_{t-1}$ exceeds the threshold values, 1% increase in gold production gives rise to 0.89% increase in GDP. It was calculated as 0.66 for regime 1, which means the same amount increase in gold production induces 0.66% increase in GDP. The elasticity of copper production growth for each regime is 1.15, which means that a 1% increase in copper growth gives rise to a 1.15% increase in GDP regardless of the regimes. Regarding LSTAR2DL-ECM model, the coefficients of the ecm_{t-1} terms were estimated as −0.29 and −0.37 for regime 1 and regime 2, respectively, which indicates that there is an error correcting mechanism in the system. As regards short-run dynamics in LSTAR2DL model, a 1% increase in copper production brings about 0.68% increase in economic growth in regime 1 and 0.23% one in regime 2. The effect of a 1% increase in gold production was estimated as 0.52% for regime 1 and 0.44% for regime 2. The short-run effects of the precious metals on economic growth are positive in LSTAR2DL-ECM model as they are in LSTAR2DL model.

For LSTARDL and LSTARDL-ECM models, thresholds parameters were estimated as −0.241 and transition variable were estimated as $dlgold_{t-1}$. Accordingly, when the first lag of gold production growth rate exceeds −0.241, transition function approaches to 1 and the economy shifts to regime 2. In other case ($dlgold_{t-1} < -0.241$), the function approaches to 0 and regime 1 prevails. The transition speeds are smooth as in LSTAR2DL models. The long-run elasticities of copper production were calculated as 1.28 in regime 1 and 0.62 in regime 2, meaning a 1% percent increase in copper production gives rise to 1.28% increase in regime 1 and 0.62% increase in regime 2. The effect of copper production in regime 2 is nearly half of the effect in regime 1. The long-run elasticities of gold production were calculated as 0.47 and 0.66 for regime 1 and regime 2, respectively. So, the long run effect of gold production on economic growth is higher in regime 2. In LSTARDL-ECM model, the coefficients of ecm_{t-1} terms were estimated as −0.31 in regime 1 and -0.33 in regime 2, indicating that 31% of the deviations from the long-run are corrected in regime 1 and 33% of them are corrected in regime 2 in one period. As to short-run dynamics in LSTARDL model, a 1% increase in copper production brings about 0.46% increase in economic growth in regime 1 and 0.40% increase in regime 2. The same amount increase in gold production gives rise to a 0.60% increase in economic growth in regime 1 and 0.49% increase in regime 2. If we evaluate the long run and short-run effects of the precious metals under estimation on the economic growth of the USA as a whole, we can say that the effect is positive in both periods and regimes, yet it is higher in regime 1 in the short run. The results indicate an asymmetry in the models.

6. Conclusion

In this study, we investigated if the metal curse hypothesis is valid for top precious metal producer countries. To this end, we utilized STARDL models that allow for analyzing nonlinear regime specific long-run and short-run relationships between variables. We found a statistically significant long-run and short-run relationship between economic growth and precious metal production. If we summarize the empirical findings, we couldn't find supporting evidence for a metal curse for Canada, Philippines, Peru, South Africa and the USA. We detected each precious metal abundance has a positive effect on economic growth both in the long and short run for these countries. However, the positive effect is not same in all regimes, leading to the acceptation of asymmetry in the models. We found that copper production has a negative effect on Australia's economy in the long run, which supports metal curse while other precious metals have positive ones on it. In the short run, the effects of all precious metals are positive in crisis regime but they are negative growth regime. For Mexico, the findings do not support metal curse in the long run, but we found supporting results for metal curse for copper and gold productions in only regime 2 in the short run.

When we consider the positive effects of precious metal abundance on economic growth in the long run and short run, the findings suggest the following policy implications. The governments of precious metal producer countries should follow policies encouraging of extraction of precious metals. To continue to escape the metal curse, the governments should carry on implementing policies on strengthening the institutions, diversifying their exports and allocating appropriately the revenues got from these resources to promote economic growth.

Declaration of competing interest

None.

CRediT authorship contribution statement

Melike E. Bildirici: Writing - original draft, Formal analysis. **Seyit M. Gokmenoglu:** Writing - original draft, Formal analysis.

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Appendix A. Supplementary data

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