Resources Policy 83 (2023) 103630

Contents lists available at ScienceDirect

Resources Policy

journal homepage: www.elsevier.com/locate/resourpol

Asymmetric linkage between copper-cobalt productions and economic growth: Evidence from Republic Democratic of Congo

Jean Pierre Namahoro, Qiaosheng Wu *, Su Hui

School of Management and Economics, China University of Geosciences (Wuhan), 430074, Wuhan, China

ARTICLE INFO

Keywords:
Copper production
Cobalt in DRC
NARDL
Economic growth

ABSTRACT

This study analyzed the nonlinear asymmetric link between copper-cobalt productions on economic development, and to which extent these variables exert growth concerning capital and labor in the Democratic Republic of Congo (DRC) for 26 years. Correlation, unit root, and cointegration tests were used for the testing framework, while nonlinear Autoregressive Distributed Lags, causality test, variance decomposition, and impulse response analysis were employed for the estimation framework. The main findings showed a strong correlation between variables, and selected variables integrated in 1st order, indicate the availability of long-run cointegration relations. The long-run nonlinear asymmetric relationships were noted between economic growth and both shocks (positive and negative) to copper and negative shock to cobalt production. Capital has the highest extent of economic growth, copper contributes more than cobalt, while labor is the least contributor to economic growth in terms of variations. This study suggested the potential policy implications, which can reflect on the possible cause-led nonlinear and negative impact of the mining sector on economic growth, and strengthen the link between copper and cobalt production and growth concerning micro-economic indicators.

1. Introduction

Natural resource-rich countries are subjected to faster development than countries without valuable natural resources. Contrary, some countries gifted minerals resources are classified as low- and lower and middle-income countries, suffering from extreme poverty, and health and wealth risks for several decades (Auty and Furlonge, 2019; Bolch et al., 2022; Havranek et al., 2016; Li et al., 2013). The prior cause-led inadequate economic growth is that total extracted domestic minerals are exported to rich countries, where the mining sector intensively benefits from industrialization and development due to a higher level of manufacturing capacity. For instance, cobalt is commonly used as a response to decarbonization, digital technologies, and electric battery vehicles (Institute, n.d.; Nkulu et al., 2018). At the same time, copper has several usages, such as providing electricity and conductivity, being corrosion-resistant in energy sectors, and other important in buildings and construction areas (Li et al., 2017). This leads to higher demand for cobalt and copper, and other minerals, whereas, the global minerals demand will be tripled by the end of 2035 (Institute, 2021).

The top-one cobalt producer global[1] and higher quality copper reserves[2](Democratic Republic of Congo) is classified as a low-income country, suffering from insignificant economic growth (World Bank Group, 2015). According to (Frankel, 2011, 2012), some countries rich with natural resources suffer from the resource curse phenomena, connected to the proposed six channels: instability of product prices, permanent crowding out of manufacturing, long-term tendencies in world product prices, unstable institutions, unsustainability, war, and cyclical Dutch diseases, lead to undesirable side effect on economic growth. Additional to these six channels, DRC' economy has experienced the natural resource curse, linked to a high-risk,[3] such as political instability, conflict in the eastern part,[4] and security risks stressed by a lack of robust infrastructure, health risks for miners, create an armed fight over

* Corresponding author.
E-mail addresses: jpnama@cug.edu.cn (J.P. Namahoro), qshwu@cug.edu.cn (Q. Wu), sh_cug@163.com (S. Hui).

[1] In 2012, Democratic Republic of Congo has about 55% of the global cobalt production, and about 70% of global cobalt has extracted in DRC (2020) (USGS, 2020b).

[2] It estimated that some of the copper reserves contain copper grades more than 3%, which is greater than the global average of 0.6–0.8% in 2012-13.

[3] Although cobalt and copper are not classified as conflict minerals (Department, 2017), Annex II of OECD indicates the need for companies to protect human rights and aware of conflict in their mineral supply chains.

[4] The eastern region of DRC is the key mining sector of cobalt and copper and other minerals.

https://doi.org/10.1016/j.resourpol.2023.103630
Received 21 April 2022; Received in revised form 6 January 2023; Accepted 24 April 2023
Available online 5 May 2023
0301-4207/

resources, and degrade the environment in the Eastern and southern regions of Africa (Caramento and Messages, 2020; Department, 2017; Katz-Lavigne, 2019; Linnecke, 2016). Boschini et al. (2007) showed that these challenges lead to economic structural changes, which significantly disturb the positive contribution of metal production, including copper-cobalt production to economic growth, and supported by Katz-Lavigne (2019) for the case of plural mining rights regime in DRC. On the other hand, sensible macroeconomic policies and structural economic reforms, and the mining sector reasonably contribute to reducing the DRC's external debt and boosting growth between 2009 and 2014 (Ober, 2016; Shengo et al., 2019). Furthermore, DRC's mining sector presents high global opportunities due to its exclusive global ranking with considerable unexploited cobalt and high-grade copper reserves, which attract several mining companies from the US, China, UK, Canada, and Australia (Börzel and Hönke, 2010; Calvão et al., 2021). Therefore, determining the influence of cobalt-copper production on economic development with considering externalities, which cause nonlinear effects, would bring the potential impact to scientific discovery in the mining sector. Notwithstanding the positive outlook of macroeconomic spikes, the contribution of microeconomic indicators, such as capital and labor to economic growth was rarely discussed, while several policies were implemented to extract a higher production of minerals in DRC (Pourret et al., 2015). However, it is interesting to examine to which extent copper-cobalt production exerts economic growth concerning capital and labor in DRC.

Although some studies have discussed the relationships between some mineral production, using linear and nonlinear causality tests (Bildirici and Turkmen, 2015; Fernandez, 2014), existing literature discussed the economic growth-natural resources nexus in top-rich countries and natural resources-rich countries. These studies used various econometrics methods, such as Dynamic Ordinary Least Square (DOLS), Vector Error Correlation Models (VECM), the theory of cointegrated process, and others (Bildirici and Gokmenoglu, 2019; Ghosh, 2006; Jaunky, 2012, 2013; Labson and Crompton, 1993). In the last three decades, empirical studies revealed that the utmost countries-in-rich with natural resources could not reach sustainable economic growth (Auty and Warhurst, 1993; Auty, 1990; Auty and Furlonge, 2019; Karl, 1997). Ahmed et al. (2016) argued that natural resources harmfully affected economic development. On the other hand (Amiri et al., 2019; Boschini et al., 2007), suggested that natural resources have a reasonable input to boost a country's economy with the condition that political economy and adequate level of institution quality are well-established in the country involved in the study. VECM was used to estimate the dynamic linkage between natural resources and economic growth in Algeria. Findings revealed that natural resource rents significantly raise the country's economy (Hamdi and Sbia, 2013). After controlling economic growth determinants, including capital stock, labor, and financial development, Satti et al.,(2014) argued that the richness of natural resources harmfully impacts economic growth, and the two-way directional causal relation linked natural resources and economic growth in Venezuela. Recently, Ben-Salha et al. (2018) have used pooled mean group estimator (PMG) to explore the link between natural resources and growth in a sampled top resource-rich countries from 1970 to 2013, a feedback causal link was identified between those two variables, the phenomena of natural resource curse has been rejected in long-term. Allcott and Keniston (2018) argued that natural resource positively moves economic development in America.

Very few studies studied the side-effect of specific minerals on growth in the economy. Tilton (1989) revealed that an increase in the economy inspires consuming industrial metal in OECD, USA, and Japan. In 20 top-rich countries, the panel dynamic ordinary least square method has been employed to detect the association between economic growth and aluminium consumption from 1970 to 2009, significant increment in an economy has led to an increment in aluminium consumption, and vise-versa (Jaunky, 2012). High demand for zinc, lead, and copper has been noticed in several countries, particularly, copper consumption dominated other metals, which leads to a challenge to the global economy (Roberts, 1996). The mean copper content of extracted ores trends and their role in economic development were investigated in regions. The average grades of copper from Africa and Australia were higher than global copper production, decreasing trends were observed in Latin America and the least copper production was seen in North America. Besides, the influence of mining operators on economic growth is more reasonable due to the dynamic fluctuations in the copper price and copper reservoir problems (Crowson, 2012). The causal link between economic growth and copper consumption in the 16 top-rich countries (Jaunky, 2013). Thus, the effect of cobalt production on DRC development was not debated country-specifically, and this motivates this study to examine the effect of cobalt coupled with copper production on economic growth in DRC.

Most recent literature on the natural resources and growth nexus ignored the possible nonlinearity relations between variables, which can be due to the externalities, such as structural economic reforms, environmental factors, and conflict minerals (Doucouliagos and Paldam, 2009; Haber and Menaldo, 2011; Weber, 2012; Williams, 2011). These studies disagree the extent of natural resources richness may asymmetrically impact the growth of the economy and disagree with common features prompting the asymmetry. According to Shin et al. (2014), asymmetry is vital to the human condition and nonlinearity is prevalent across social sciences. Again, the use of the time-varying regression model, which has constant parameters by assuming that a variation in the explanatory variables has an identical impact over time can be invalid within all conditions. Moreover, Enders (2015) suggested that employing symmetric methods to estimate causal links that can have possible asymmetry could lead to inappropriate decisions. The nonlinear approaches, which can detect the asymmetric effect of specific minerals on economic growth are rarely employed. Ampofo et al. (2020) employed a nonlinear method, which is nonlinear autoregressive distributed lags (NARDL) built by Shin et al. (2014). Their findings showed that both shocks (positive and negative) to natural resource rents harm DRC development. Therefore, using NARDL to investigate the asymmetric impact of cobalt and copper production on economic growth can provide scientific support to policymakers in the mining sector and economic development in DRC.

This study, however, aims to fill the gaps and add input to the existing related studies on the natural resources-growth nexus by detecting the asymmetric relationships between copper and cobalt production on the economic development in DRC for 26 years. This country was selected among others due to it is the top-one producer of cobalt and has a higher quality of copper reserves around the globe. Microeconomic indicators, such as capital and labor have been used in the multivariate framework as control variables due to the dependence between them and economic growth.

This study identified three features that differentiate it from previous literature that explored the impact of specific minerals on economic growth: Firstly, this article is the first to explore the asymmetric linkage between cobalt-copper productions and economic growth in DRC. Secondly, this study is the first that determines to which extent copper-cobalt productions exert economic growth concerning existing microeconomic indicators. Findings can assist policymakers to comprehend and monitor the impact of copper-cobalt production within the existence of other main economic indicators. Thirdly, this study employed the most recent NARDL, which is the potential to examine the nonlinear and asymmetric relationships between variables. Different from other econometric models used in existing studies on natural resources-growth nexus, NARDL can test long-, and short-run asymmetric relationships between variables. To effectively access the causality relationships between shocks to copper-cobalt production and growth, a nonlinear causality test (Hiemstra and Jones, 1994)extended by (Kyrtsou and Labys, 2006) has been employed. Moreover, this study used variance decomposition and impulse response approach, which is the potential to determine to which extent explanatory variables exert the variable of interest, as argued by Lanne and Nyberg (2016).

In brief, this article contributes to comprehending the nonlinear asymmetric relation of cobalt and copper productions on economic growth and determining to which extent these minerals exert growth concerning existing microeconomic inputs. The most recent nonlinear approach and variance decomposition and impulse response have been employed. We focused on the top-one country in cobalt production and the highest copper reserves on the globe for the period 1990 to 2016. The findings and policy implications of this study will awaken policy-makers and governments to reflect on possible cause-led nonlinear effects of copper-cobalt production on economic growth and establish relative policies.

2. Data and methods

This part introduces data, multivariate model, econometric frameworks (unit root tests, nonlinear ARDL, bound test, and causality test) of the selected variables, variance decomposition and impulse response approach, and nonlinear causality test, see Fig. 1 for the methodological framework of the study.

2.1. Data

The time-varying data from 1990 to 2016, extracted from the (Bank, 2020), U.S. Geological Survey (USGS, 2020a), and Trading Economics (TE, 2021) known as the International market of natural resources databases have been applied. Annually total refined copper and cobalt productions are converted from metric tons to pounds. Again, yearly historic copper and cobalt prices on the international market have been employed to approximate the aggregate yearly income from cobalt and copper productions. The nominated variables were shifted to per capita and then converted into the natural logarithm to avoid possible heteroscedasticity and achieve a robust analysis. National GDP per capita has applied as economic growth, while capital and asset, and labor have employed regulators. Table 1 and Fig. 2 show the descriptive statistics and trends of all selected variables from 1990 to 2016, respectively.

Table 1
Descriptive statistics of selected variables.

	lnGDP	lnCop	lnCup	lnC	lnLab
Mean	2.561	0.392	1.356	1.685	−0.426
Median	2.538	0.408	1.310	1.612	−0.411
Maximum	2.846	1.435	2.094	2.193	−0.409
Minimum	2.440	−0.385	0.715	1.316	−0.465
Std. Dev.	0.101	0.462	0.498	0.309	0.022
Observations	27	27	27	27	27

2.2. Mathematical model

The focus of our study is to explore the asymmetric relations between copper-cobalt production on economic growth in the Democratic Republic of Congo. To effectively estimate the impact of copper and cobalt productions, the main input of production function (Douglas, 1976), is applied as regulatory variables, such as capital and labor. After the possible transformation, the link between variables is presented in the following mathematical expression:

$$lnGDP_t = \alpha_0 + \alpha_1 lnLab_t + \alpha_2 lnC_t + \alpha_3 \ ln\ Cop_t + \alpha_4 \ ln\ Cup_t + u_t \tag{1}$$

For $t = 1, 2, \ldots T$ is the length of time, GPD_t is the economic growth, Lab_t is labor, C_t is the capital, while Cop_t, and Cup_t are cobalt and copper production, respectively. α_0 is the fixed effect, $\alpha_1 - \alpha_4$ are the regression coefficients to be estimated, and u_t is the residual.

2.3. Methods

2.3.1. Unit root tests

To fully detect the asymmetric relationship between copper-cobalt production and economic growth in DRC, it is important to verify the correlation between variables and check the unit root of selected variables. In this case, unit root tests proposed by Dickey and Fuller (Harris, 1992), and Phillip Perron (Kim and Perron, 2009) have been employed. These tests rely on the null hypothesis of unit root existence in the variable. Their results were compared with those obtained from another test by Kwiatkowski, Phillips, Schmidt, and Shin (KPSS) (Kwiatkowski et al., 1992a) to see whether the results can provide similar conclusions. Due to the main focus of this study is to estimate the nonlinear impact of copper-cobalt production on economic growth, the famous unit root results should be compared with those estimated from the nonlinear unit root test proposed by test for nonlinear unit root (Kapetanios et al., 2003). Sometimes, the variable can have breakpoints and roots, which can lead to imprecisions in the forecast as well as failure to reject the null hypothesis. In this respect, Kim and Perron developed a statistical test for removing redundant breakpoints in the variable (Kim and Perron, 2009). Mathematically, these tests are expressed in the following equation:

$$\Delta y_t = \mu y_{t-1} + \sum_{i=1}^{p} \pi_i \Delta y_{t-i} + u_t \tag{2}$$

For $\mu = 1$ (null hypothesis by using DF test), $\pi_i = 1, \mathrm{i} = 1, 2, \ldots, \mathrm{p}$ unit root at P optimal lag (p) by using ADF and PP unit root tests, Δ indicates the operator for 1st and 2nd differences orders, and u residual. The nonlinear unit root of (Kapetanios et al., 2003) is mathematically presented in the following equation:

$$\Delta y_t = \varphi y_{t-1} + \gamma y_{t-1}\left[1 - \exp\left(-\theta y_{t-d}^2\right)\right] + \varepsilon_t \tag{3}$$

The conversional suggestion from using this test relies on the larger the deviation from the series, the stronger the tendency to move back to equilibrium, which implies that when $\varphi \geq 0$ then $\gamma < 0$ and $\varphi + \gamma < 0$ for the process to be globally stationary. For more detail on parameters, see (Kapetanios et al., 2003).

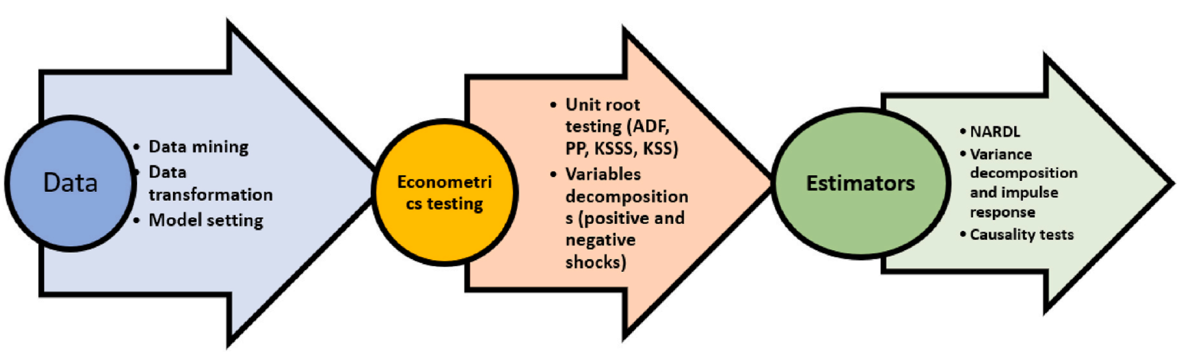

Fig. 1. Methodological framework.

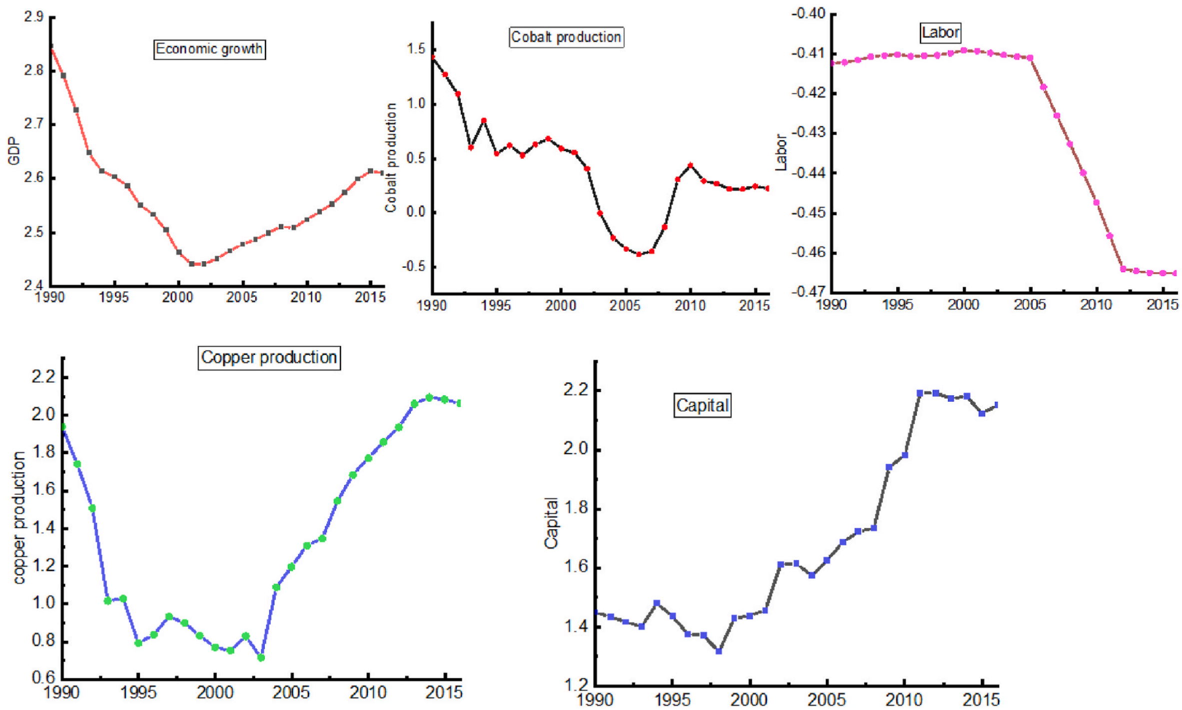

Fig. 2. Trends of copper-cobalt production from 1990 to 2016.

2.3.2. Nonlinear autoregressive distributed lags approach

The prior role of this article is to explore the presence of nonlinear relationship asymmetry and symmetry between copper-cobalt productions and economic growth in DRC. In this case, a recent approach proposed by (Shin et al., 2014), which is nonlinear Autoregressive Distributed Lags (NARDL) has employed estimated the possible nonlinear asymmetries between variables. The importance of the NARDL approach is its efficiency and ability to be employed for time-varying variables co-integrated at one or zero, and a combination of these orders. Since NARDL is sensible on integration orders, the Johansen cointegration test (Johansen, 1992) has been used to check the cointegration orders of involved variables. We, therefore, applied the BDS test of (Broock et al., 1996) to detect whether there is a nonlinear dependence between time-series variables. The agreements of these two tests allow NARDL to deeply examine the nonlinearity impact exerted between variables (Shin et al., 2014). The next step to use NARDL is variable decomposition, to effectively examine nonlinearities. Hence, Hatemi-j (2012) proposed a potential test to decompose regressors into new variables/shocks (positive and negative changes, in the following:

$$x_t^+ = \sum_{j=1}^{t} \Delta x_j^+ = \sum_{j=1}^{t} max\left(\Delta x_j, 0\right), x_t^- = \sum_{j=1}^{t} \Delta x_j^- = \sum_{j-1}^{t} min\left(\Delta x_j, 0\right) \quad (4)$$

Employing these positive and negative shocks (Eq. (3)) as new variables in Eq. (1) coupled with the error-correction term leads to nonlinear asymmetric effects and their dynamic multipliers, and then checked by a test based on statistical inference in vector Autoregressive (Toda and Yamamoto, 1995). We, therefore, can write equation (1) as follow:

$$\begin{aligned} \Delta \ln(y_t) = \delta_0 + \sum_{l=1}^{p} \rho_1 \Delta ln\, y_{t-l} + \sum_{l=0}^{q} \beta_1^+ \Delta ln\, x_{t-l}^+ + \sum_{l=0}^{q} \beta_1^- \Delta ln\, x_{t-l}^- \\ + \sum_{l=0}^{q} \theta_1^+ ln\, x_{t-l}^+ + \sum_{l=0}^{q} \theta_1^- ln\, x_{t-l}^- + \rho_2 \ln y_{t-1} + \theta_2^+ \ln x_{t-1}^+ \\ + \theta_2^- \ln x_{t-1}^- + u_t \end{aligned} \quad (5)$$

Where β_j and θ_j are long- and short-run asymmetry (coefficients), respectively, and long-run adjustment rates; ρ_1 and ρ_2 are the lagged effect; y_t is the economic growth per capita, x_t indicates the labor, capital, copper, and cobalt productions in Eq. (1).

To test the asymmetry and symmetry relations, Shin et al. (2014) proposed the bound test, relying on pair of statistical tests: Fisher test (F-test) relies on this hypothesis: $\beta = \beta^+ = \beta^- = 0$, or $\theta = \theta^+ = \theta^- = 0$ (null hypothesis), for co-integration at 1st order, and student test (t-statistic) with this hypothesis: $\beta = 0$ or $\beta \prec 0$ for co-integration at zero order for all regressors in the model. Failing to reject the null hypothesis implies that there is a asymmetric/symmetry long- or short-run relationship between transformed regressors and economic growth.

2.4. Causality test

Since the causality to be tested is nonlinear, the nonlinear causality technique has been employed initially to check whether the series exerts a causality effect between them. In this context, the nonlinear causality test proposed by(Hiemstra and Jones, 1994) was extended by (Kyrtsou and Labys, 2006). Among the famous causality hypothesis (bidirectional, unidirectional, and neutral), the nonlinear causality test is used to confirm that at least one directional causation must be obtained between variables, allowing to check the nonlinear causality in terms of positive and negative shocks. To capture possible asymmetries link into account by making the cumulative sums of positive and negative variations in fundamental variables, the asymmetric causal test proposed by (Hatemi-j, 2012) has been employed. The asymmetric relationships between variables examined by using the Wald test are expressed as follows:

$$Wald = (cb)'\left[c\left(z'z\right)^{-1} \otimes S_u)c\right)^{-1}\right](cb) \quad (6)$$

Matrix coefficients of vector autoregressive (VAR) model represented by b, while pointer matrix with elements ones for constrained parameters and zeroes for the remaining constraints is c, which is equivalent to $p \times n(1 + np)$, $\otimes$ indicates the Kronecker product, and the variance-covariance matrix of the VAR model is S_u and other parameters are explained in (Hatemi-j, 2012).

2.5. Variance decomposition and impulse response approach

To fully scrutinize the share of copper-cobalt productions in economic growth concerning existing input in an economy of DRC, impulse response and variance decomposition analysis have been used. The dynamic structure of this approach assists to transmit the impact of exogenous variables to the response variable or itself. According to Lanne and Nyberg (2016), the impulse response estimates located in a steady companion-matrix of the VAR model, expressed in the following relation:

$$y_t = \sum_{j=0}^{P} \vartheta_i y_{t-i} + \varepsilon_t \tag{7}$$

For P is the optimal lag and ϑ_i indicates the simple impulse response function, which is computed by shifting Eq. (6) to an infinite vector moving average. Therefore, the simple impulse response function is computed as follows:

$$\vartheta_i = \begin{cases} I_{k,i=0} \\ \sum_{j=1}^{i} \vartheta_{t-j} A_j, i = 1, 2, .. \end{cases} \tag{8}$$

For A_j is the matrix coefficient of changed VAR into infinity moving average vector form and I_k is the identity element of the companion matrix. Hence, the h-step ahead predict-error has resulted in the following equation:

$$y_{t+h} - E[y_{t+h}] = \sum_{i=0}^{h-1} \varepsilon_{(t+h-1)} \vartheta_i \tag{9}$$

Where y_{t+h} is the vector at time $t+h$, while $E[y_{t+h}]$ is the h-step ahead predicted vector in time t. The cross-product of $K \times K$, noted as matrix p has been employed to orthogonalize the alteration of selected variables for detecting the share of the variable on the predict-error variance. Hence, the share of a variable n to the h-step ahead predict-error variance of variable m resulted in the following mathematical equation:

$$\sum_{i=0}^{h\ l} \theta_{nm}^2 = \sum_{i=0}^{h\ l} \left(i_m' P \vartheta_{in} \right)^2 \tag{10}$$

For i_s is the sth column of the identity matrix I_k.

3. Results and discussion

3.1. Results of correlation and unit root tests

Findings from Table .2 show the strong correlation between copper and cobalt production, and economic growth in DRC, which indicates that the income generated from copper and cobalt production has a direct positive contribution to boosting economic growth. The correlation between economic growth and capital and labor, on the other hand, is significantly positive, which implies that the famous economic determinants are contributing to increasing economic development. Regressors highly explain the change in economic growth (adjusted coefficient of determination, R-square = 0.893).

Table 2
Pearson correlation results.

	lnGDP	lnCop	lnCup	lnC	lnLab
lnGDP	1				
lnCop	0.721*	1			
lnCup	0.456**	−0.07	1		
lnC	0.420*	−0.420*	0.789*	1	
lnLab	0.461*	0.276	−840*	−0.963*	1
R-square	0.893				

* and ** are significant at 1% and 5% significance levels, respectively.

To know the levels of selected variables, ADF, PP, KSPP (Harris, 1992; Kwiatkowski et al., 1992b), and KSS (Kapetanios et al., 2003) unit root tests were employed and results are available in Tables 3a and 3b. These tests provided coinciding results, which reveal that selected variables are integrated and stationery at zero-order and first-order, implying that selected variables meet the assumption of using NARDL, and gives guarrent of employing this nonlinear estimator to bring reasonable results.

On the other hand, Perron (1989) discovered unforeseen structural variations in the series, which affect conclusions in the econometric forecast, and disturb the rejection of the stationarity hypothesis, in case the structural variations in the time-varying variable are ignored. From this fact, Kim and Perron (2009) argued that the stationarity tests can obtain unclear findings for regressors of small size included in the model. Nevertheless, to remove the unknown structural variations, the breakpoint unit root test has been employed. The findings are seen in Table.3a for both constant and drift. These results revealed that there is no unit root in selected variables, but contain structural break in 2007, 2003, 2009, 2001, and 2005 for economic growth, copper production, cobalt production, capital, and labor, respectively. The identified structural breaks indicate the presence of economic growth structural changes due to externalities that affect the input variables of an economy. Therefore, this study motivated to examine whether copper and cobalt production nonlinearly affect economic growth due to the externalities effect, such as regime changes, time-varying, war, and others.

3.2. Cointegration and BDS tests results

Table .4 reports the results from the Johansen (1992) cointegration test between cobalt-copper productions, capital, labor, and economic growth. These results reject the hypothesis of no cointegration at a 5% significant level among the selected variables. This, therefore, implies the occurrence of asymmetric long-run equilibrium relations between economic growth and cobalt-copper production, capital, and labor. We, thereafter, used the BDS test proposed by Broock et al. (1996) to check the existence of nonlinear long-run relationships. Table .5 reports the findings from the BDS test, which rejected the independent and identical results hypothesis at various embedding dimensions (m), due to the presence of strong evidence of non-linearity in all variables. In conclusion, the time-varying variables in this study are nonlinear dependent.

3.3. Results of nonlinear autoregressive distributed lagged model

The results presented in Table 6 show the nonlinear relationships among economic growth and copper-cobalt production under the control of capital and labor regarding shocks (positive and negative). From this table, a negative shock to cobalt production has a significant adverse effect on economic growth (coefficients of −0.027, at a 1% significance level), while a positive shock to copper production has a significant constructive effect (coefficient of 0.032 at 1% significance level). The positive shock to cobalt and the negative shock to copper production have insignificant positive effects on economic growth. This indicates that cobalt production nonlinearly and harmfully influences the economic development of DRC, while copper production nonlinearly and positively affects the nation's economy in long term. These findings coincide with those that Ampofo et al. (2020) estimated using NARDL on the connection of total natural resources rents and growth in DRC, results revealed that total resource rents nonlinearly and asymmetrically affect economic growth.

The further covariates (capital and labor) significantly support the increase or decrease in the economic increment in DRC. Both negative and positive surprises to capital have a significant constructive effect on economic growth with long-run coefficients of 0.092 and 0.250, respectively. A negative shock to capital has a significant negative impact in the short run, while a positive shock insignificantly affects growth. Both negative and positive shocks to labor harm economic

Table 3a
Unit root tests results with/without structural breaks.

Without structural break	KPSS		ADF		PP	
lnGDP	Level	1st diff	Level	1st diff	Level	1st diff
	−3.375**		−2.590**		−3.384**	
lnCup	−3.192**		−3.464**		−3.714**	
lnCo	−1.967	−2.351**	−2.337	−4.056**	−2.395	−4.086**
lnC	0.163	−3.543*	−2.097	−4.867*	−2.094	−4.863*
lnLab	0.187	−4.381*	−2.468	−5.272*	−1.489	−5.154*
With structural break	Trend and intercept Statistic	Break date		With the only intercept Statistic	Break date	
lnGDP	−7.591*	2007		−3.951	2003	
lnCup	−7.858*	2003		−3.858	2003	
lnCop	−4.972*	2009		−3.048	2001	
lnC	−5.639*	2001		−2.370	2008	
lnlab	−4.448	2005		−5.279*	2005	

* and ** are significant at 1% and 5% significance levels respectively.

Table 3b
KSS nonlinear unit root results.

variables	levels	1st difference	maxlags
lnGDP	−2.921**	−4.255*	2
lnCup	−1.728	−3.124**	2
lnCop	−1.356	−2.863***	2
lnC	−1.672	−3.748**	2
Lnlab	−1.572	−2.771***	2

*,**, and *** indicate the significant at 1%, 5%, and 10% significance levels, respectively.

growth, this impact is significant for a negative shock with the long-run coefficient of −0.632, significant at 5%. The overall results show that the effect degree of shocks to capital is bigger than those estimated from cobalt and copper production, which implies that capital can control the effect of other variables in the production function. Fig. 3 shows that cumulative sum and cumulative sum of squares errors, both are within the critical limits at a 5% level, which implies that the used estimator is steady and reliable to provide the long-run nonlinear coefficients.

Table .7 shows findings from the Wald test, which strengthens the nonlinear asymmetric link noted between economic growth and its determinants indicated in Table .6. The findings confirm the existence of a nonlinear long-term asymmetric link between both positive and negative shocks to copper production and economic development. The nonlinear asymmetric relation is confirmed between growth and negative shock to cobalt production. The long-term nonlinear relation

Table 4
Results from Johansen Cointegration test.

Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	Critical Value at 5%	P-values
None [a]	0.733	83.308	60.061	0.000
At most 1 [a]	0.567	50.255	40.174	0.003
At most 2 [a]	0.447	29.319	24.275	0.010
At most 3 [a]	0.423	14.473	12.320	0.021
At most 4	0.028	0.719	4.129	0.455

[a] Rejection of the hypothesis at the 5% significance level.

Table 5
BDS test results.

	m = 2	m = 3	m = 4	m = 5	m = 6
lnGDP	0.184[a]	0.305[a]	0.390[a]	0.455[a]	0.490[a]
lnCup	0.147[a]	0.220[a]	0.242[a]	0.243[a]	0.220[a]
lnCop	0.177[a]	0.291[a]	0.354[a]	0.381[a]	0.370[a]
lnC	0.149[a]	0.241[a]	0.269[a]	0.253[a]	0.176[a]
lnlab	0.149[a]	0.215[a]	0.218[a]	0.157[a]	−0.008

[a] Indicates a significance level of 1%.

Table 6
Long-run estimates from the NARDL approach.

Dependent	**Diff(lnGDP)** coefficients	t-stat	p-value
lnCop(+)	0.003	0.256	0.800
lnCop(−)	−0.027*	−3.015	0.006
lnCup(+)	0.032*	4.592	0.000
lnCup(−)	0.026	0.993	0.331
lnC(+)	0.092*	5.725	0.000
lnC(−)	0.250**	2.802	0.012
DlnC(+)	0.034	0.937	0.361
DlnC(−)	−0.262**	−2.186	0.043
lnlab(+)	−8.497	−0.679	0.504
lnlab(−)	−0.632**	−2.220	0.038

Note: * and ** are significant at 1% and 5%, respectively.

between a positive shock to capital and growth is supported together with both negative and positive shocks to labor.

Lastly, Fig. 4A-D shows dynamic multiplier adjustments, which are the asymmetric relationships in terms of positive and negative shocks to copper-cobalt productions on economic growth. From Fig. 4-A, the adjusted economic growth is directed to the long-run rapid raise concerning positive and negative shocks in cobalt production over various lengths of time. The negative shock dominates a positive shock to cobalt production, which indicates that cobalt has a nonlinear negative asymmetric effect on economic growth, increasing through time. In Fig. 4-B, positive shock surplus negative shock to copper production influence growth and stimulated symmetrically and slightly increment with economic growth. Fig. 4-C reveals that firstly, negative shock dominates positive shock to capital to influence economic growth. After, positive shock dominates negative shock to affect economic growth and stimulated symmetrically with economic growth. Fig. 4-D reveals that positive shocks dominated by negative shocks to labor negatively disturb economic growth. Therefore, the nonlinear asymmetric effect of cobalt and copper production on economic growth is noted, but growth curves remain in a positive direction. On the contrary, the nonlinear asymmetric effect of capital and labor causes economic growth to be in a negative direction.

3.4. Causality results

Table .8 presents the initial results for confirming the nonlinear causality relationships between cobalt-copper production and economic growth. To go on with these results (Hiemstra and Jones, 1994; Kyrtsou and Labys, 2006), have employed. In the findings from one to five lags, the unidirectional causal hypothesis runs from economic growth to copper production at the 1st and 4th lags, and one run from copper production to growth is noted at the 2nd and 5th lags. The unidirectional

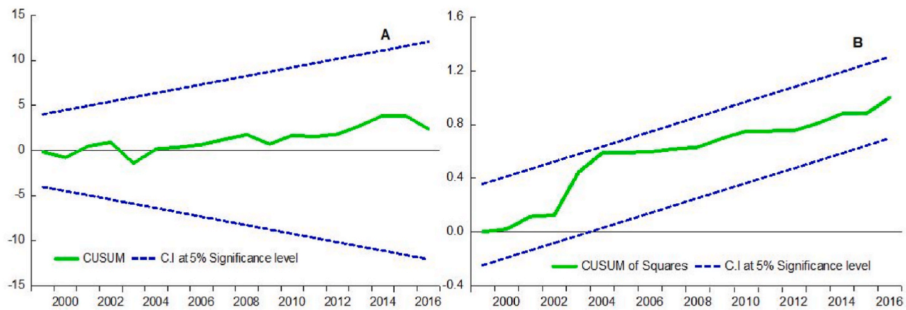

Fig. 3. The plots of the cumulative sum (A) and cumulative sum of squares (B) errors, where blue-dash lines indicate critical limits at the 5% level.

Table 7
Wald test for long-run asymmetry restrictions.

Variables	Wald test	Variables	Wald test
$\mathbf{LCop_t^+}$	0.065	$LCop_t^-$	9.093*
$\mathbf{LCup_t^+}$	21.091*	$LCup_t^-$	11.074*
$\mathbf{LC_t^+}$	16.420*	LC_t^-	2.455
$\mathbf{Llab_t^+}$	9.340*	$Llab_t^-$	4.930**

*, **, and *** are significant at 1%, 5%, and 10%, respectively, while "+", and "-" indicate positive and negative shocks, respectively.

causal hypothesis runs from cobalt production to growth at the 3rd lag, and the unidirectional causal link runs from capital to growth are noted in several lags. These results confirm the existence of nonlinear causal relationships between growth and cobalt-copper production in DRC. Table 9 presents the main results from the nonlinear causality test proposed by (Hatemi-j, 2012) on asymmetric causation between cobalt-copper production and economic growth in terms of shocks, under the control of capital and labor. From this table, nonlinear asymmetric causation, which runs from negative shock to cobalt production to economic growth is noted, this implies that some external factors create variations in cobalt production, and lead to nonlinear causation to economic growth. This supports studies that classified some minerals in the mineral conflict list (Doucouliagos and Paldam, 2009; Haber and Menaldo, 2011; Katz-Lavigne, 2019; Weber, 2012; Williams, 2011). A conservative nonlinear asymmetric causation, which runs from economic growth to negative and positive shocks to copper production is noted, this indicates that some share of growth is probably used in copper production. On the other hand, a conservative causal relation, which moves from economic growth to negative shocks and other runs from positive shock to capital is noted. The neutral causal links are noted between shocks to labor and other shocks to capital, copper, and cobalt production. These results indicate that the mineral sector in DRC has faced several externalities, which lead to nonlinear effects from certain minerals, such as copper and cobalt production.

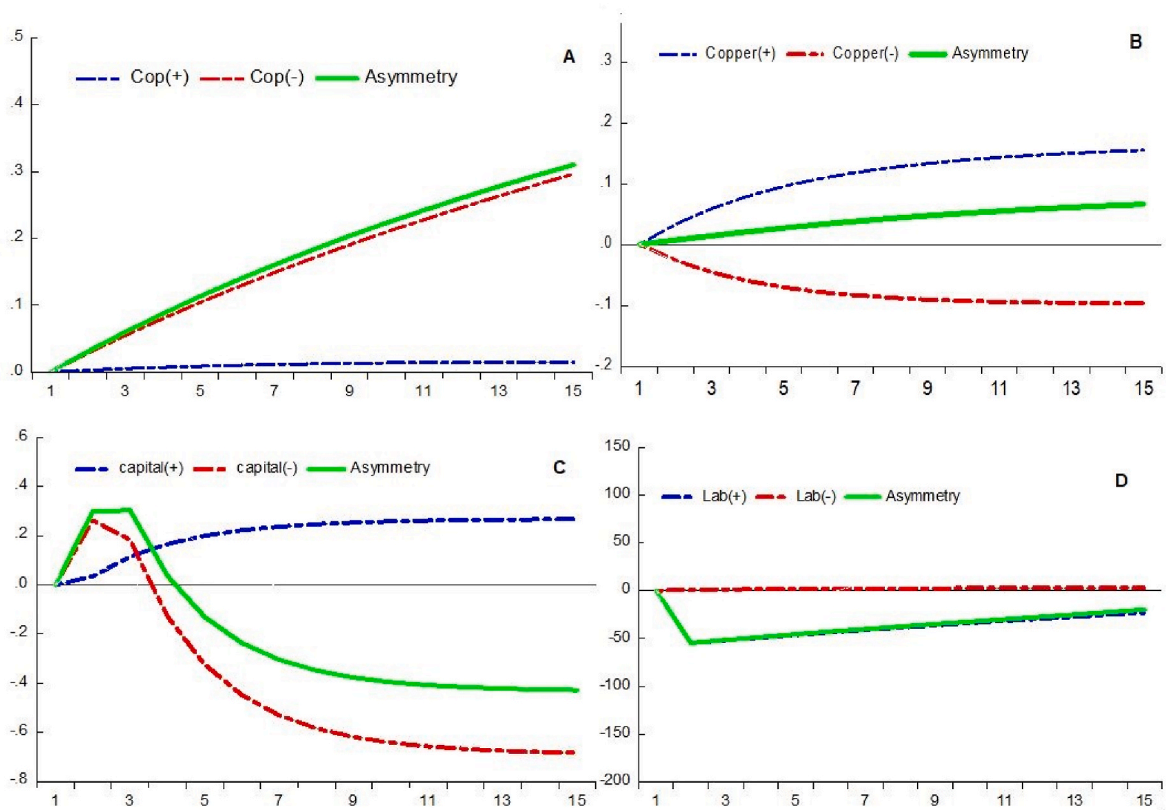

Fig. 4. Multiplier figures show the cumulative influence of cobalt-copper productions, capital, and labor on economic growth.

Table 8
Results from Hiemstra–Jones causality test.

lags	$\Delta lnGDP_t \rightarrow \Delta lnCup_t$	$\Delta lnCup_t \rightarrow \Delta lnGDP_t$	$\Delta lnGDP_t \rightarrow \Delta lnCb_t$	$\Delta lnCb_t \rightarrow \Delta lnGDP_t$	$\Delta lnGDP_t \rightarrow \Delta lnC_t$	$\Delta lnC_t \rightarrow \Delta lnGDP_t$	$\Delta lnGDP_t \rightarrow \Delta lnLab_t$	$\Delta lnLab \rightarrow \Delta lnGDP_{tt}$
1	10.876*	0.030	0.495	0.306	0.327	3.002***	0.485	0.802
2	2.133	4.083**	1.529	0.243	0.019	2.249	0.331	0.831
3	1.039	0.418	2.230	4.172*	1.714	2.816***	0.254	0.579
4	4.547**	1.829	1.452	1.315	1.556	3.130***	0.777	0.288
5	1.273	5.060*	0.268	1.040	2.493	3.441**	0.591	0.397

Table 9
Results from the causality test.

Variables	**Hypothesis**	**statistic**	**p-value**	**variables**	**hypothesis**	**Statistic**	**p-value**
lnCop	$y_t \rightarrow Cop_t^+$	0.106	0.899	lnC	$y_t \rightarrow C_t^-$	3.438***	0.053
	$Cop_t^+ \rightarrow y_t$	1.283	0.300		$C_t^- \rightarrow y_t$	2.234	0.134
	$y_t \rightarrow Cop_t^-$	1.631	0.221		$y_t \rightarrow C_t^+$	0.994	0.388
	$Cop_t^- \rightarrow y_t$	4.304**	0.028		$C_t^+ \rightarrow y_t$	2.847***	0.082
lnCup	$y_t \rightarrow Cup_t^-$	4.213**	0.030	lnlab	$y_t \rightarrow lab_t^-$	1.080	0.359
	$Cup_t^- \rightarrow y_t$	2.132	0.146		$lab_t^- \rightarrow y_t$	2.425	0.115
	$y_t \rightarrow Cup_t^+$	3.565**	0.045		$y_t \rightarrow lab_t^+$	0.127	0.881
	$Cup_t^+ \rightarrow y_t$	2.105	0.149		$lab_t^+ \rightarrow y_t$	2.019	0.160

** and *** indicate significance levels at 5% and 10%, respectively.

3.5. Variance decomposition and impulse response results

To estimate which extent to which cobalt and copper production, capital and labor can exert economic growth in DRC, the impulse response and variance decomposition approach proposed by (Lanne and Nyberg, 2016) has been employed. Verdicts from variance decomposition and impulse response analysis for 10 years predict time are reported in Table 10. The results show that 14.571% variations in economic growth can be explicated by innovative shocks of growth itself, cobalt and copper production will contribute 0.921% and 6.138% variations in economic growth, respectively, and 78.116% and 0.252% variations in economic growth can be explained by capital and labor, respectively. From these findings, capital will higher contribute to economic growth more than other variables, copper production also will contribute to growth more than cobalt production in the next 10 years prediction horizon. This implies that the economic growth of DRC will highly depend on capital and copper production, while labor will least contribute.

Fig. 5 shows the accumulated response from copper and cobalt production, capital, and labor to economic growth in terms of innovative shocks. From the figure, the variation of economic growth itself has an increment trend up to 10 years forecast horizon. These results indicate an increase in economic determinants, including capital and copper production. The involvement of cobalt production in growth appears to be slightly increased up to 10 years. The variation of copper production on economic growth has seen a steady increase in the first six years and decreased in the next four years. The labor and capital variations to growth are slightly related to those from copper-cobalt productions. This specifies that copper-cobalt production will support economic growth more than capital and labor in DRC.

Table 10
Impulse response and variance decomposition results.

Response variable	**period**	**Impulse variable**				Labor
		GDP	Cobalt	Copper	Capital	
GDP	10	14.571	0.921	6.138	78.116	0.252
Cobalt	10	58.650	12.145	1.060	9.869	18.274
Copper	10	24.240	11.104	26.707	37.871	0.075
Capital	10	0.623	13.742	28.943	46.782	9.908
Labor	10	2.667	1.196	43.789	26.210	26.136

4. Conclusions and policy implications

This study examines the nonlinear and asymmetric impact of cobalt-copper production on economic growth in the Democratic Republic of Congo from the period of 1990–2016. To efficiently detect the impact of cobalt-copper productions, current microeconomic indicators, including labor and capital are applied as regulators in the production function. The initial step is for testing selected variables by employing correlation, unit root, and cointegration tests, while in the next step, NARDL, and causalities are applied to achieve the nonlinear asymmetric relationship between variables. Lastly, variance decomposition and impulse response analysis has been employed to determine which extent copper-cobalt production exerts on economic growth.

The findings of this study are as follows: firstly, the correlation test confirms the direct effect of copper-cobalt production on economic growth, while famous unit root tests and nonlinear unit root tests have rejected the null hypothesis of unit root at 1st difference, and all variables are cointegrated at 1st integration order. Secondly, the results from NARDL revealed that positive shock to copper production and negative shock to cobalt production significantly impact economic growth negatively and positively, respectively, while positive shock to cobalt production and negative shock to copper production have insignificant positive effects on economic growth. Economic growth determinants, such as positive shocks to capital noted to positively affects economic growth.

Thirdly, the nonlinear asymmetric test confirms the nonlinear and asymmetric link between both shocks (positive and negative) to copper and negative shock to cobalt production and economic growth in the long run. The long-run nonlinear asymmetric relation was noted between a positive shock to capital and growth, and between both negative and positive shocks to labor and economic growth.

Fourth, the initial results from the nonlinear causality test for confirming the nonlinear causal link between copper-cobalt production and economic growth reveal unidirectional causation in various lags between copper and cobalt production and economic growth. Then, the causality test shows a one-way causal link between a negative shock to cobalt and growth, negative and positive shocks to copper production and growth, and negative shocks and positive shocks to capital and growth. Fifth, results gained from variance decomposition analysis and impulse response indicate that capital is the furthermost causative microeconomic indicator of growth due to its high variations, copper contributes more than cobalt to growth, while labor is the least contributor to economic growth due to its least variations.

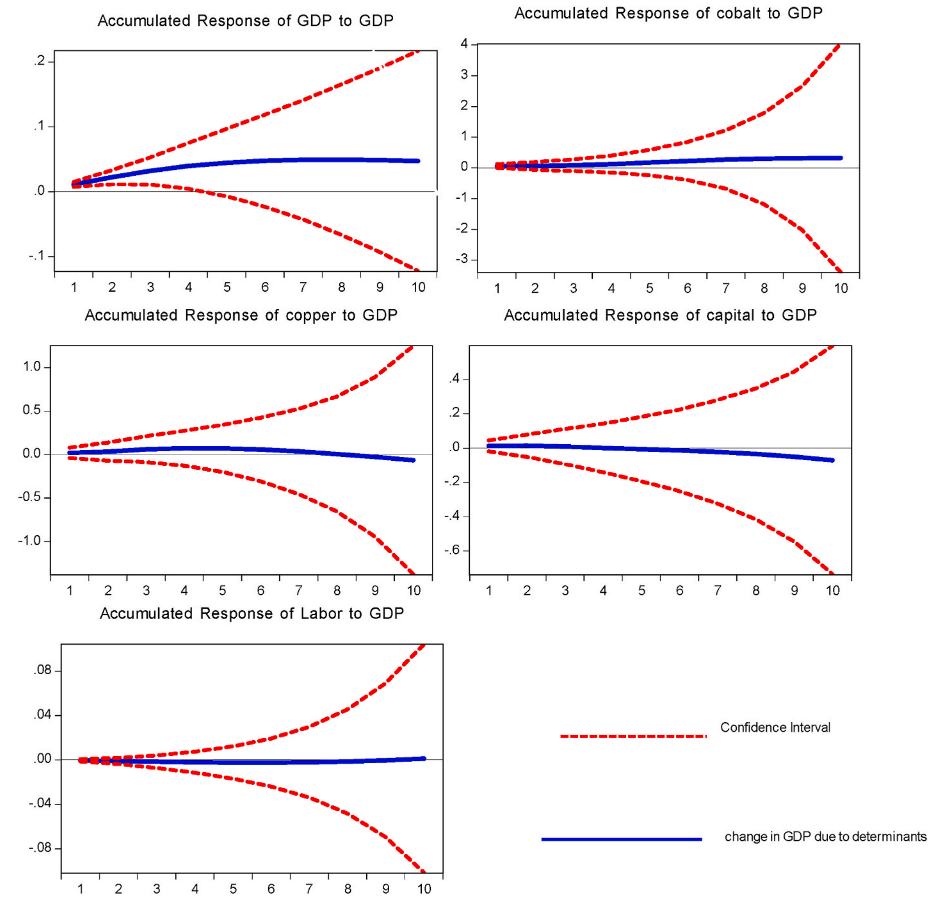

Fig. 5. Impulse response of copper and cobalt production, capital, and labor on economic growth for prediction of 10 years (blue color) with a 95% of confidence interval (red color).

Concerning the study findings, the important policy implications to the policymakers are: firstly, policymakers need to reflect on cause-led nonlinear asymmetric relationships between cobalt and copper production on economic growth, such as mineral conflict, mineralogy policy reforms, structural economic reforms, and other. The mining sector ought to be restructured so that cobalt and copper production could be positively contributing to boosting economic growth. Concerning the presence of microeconomic indicators, the mining sector can be added to the secured economic growth determinants. Secondly, though, the cobalt-copper production effect degree is weaker related to other causal effects from present contributors to economic development, cobalt, and copper mining actions and industrialization can be strictly monitored to achieve sustainable development. The labor and capital variabilities should control the effect of cobalt-copper production on economic growth to maintain economic growth stability in the country.

Credit of authors statement

JEAN PIERRE NAMAHORO: substantial contribution to conception and substantial contribution to acquisition of data, substantial contribution to analysis-interpretation, drafting the article and methodology, critically revising the article for important, final approval of the version to be published, QIAOSHENG WU: critically revising the article for important, final approval of the version to be published, Fundings, SU HUI: critically revising the article for important, final approval of the version to be published.

Declaration of competing interest

The authors declare that there is no conflict of interest.

Data availability

The data that has been used is confidential.

Acknowledgment

This study was supported by the National Social Science Foundation of China (grant number: 19ZDA112) and the National Natural Science Foundation of China (grant number: 71991482).

References

Ahmed, K., Mahalik, M.K., Shahbaz, M., 2016. Dynamics between economic growth, labor, capital and natural resource abundance in Iran: an application of the combined cointegration approach. Res. Pol. 49, 213–221. https://doi.org/10.1016/j.resourpol.2016.06.005.

Allcott, H., Keniston, D., 2018. Dutch disease or agglomeration? The local economic effects of natural resource booms in modern America. Rev. Econ. Stud. 85, 695–731. https://doi.org/10.1093/restud/rdx042.

Amiri, H., Samadian, F., Yahoo, M., Jamali, S.J., 2019. Natural resource abundance, institutional quality and manufacturing development: evidence from resource-rich countries. Res. Pol. 62, 550–560. https://doi.org/10.1016/j.resourpol.2018.11.002.

Ampofo, G.K.M., Cheng, J., Asante, D.A., Bosah, P., 2020. Total natural resource rents, trade openness and economic growth in the top mineral-rich countries: new evidence from nonlinear and asymmetric analysis. Res. Pol. 68, 101710 https://doi.org/10.1016/j.resourpol.2020.101710.

Auty, R., Warhurst, A., 1993. Sustainable development in mineral exporting economies. Res. Pol. 19, 14–29. https://doi.org/10.1016/0301-4207(93)90049-S.

Auty, R.M., 1990. Resource-based Industrialization: Sowing the Oil in Eight Developing Countries.

Auty, R.M., Furlonge, H.I., 2019. The Rent Curse: Natural Resources, Policy Choice, and Economic Development. Oxford University Press, USA.

Bank, T.W., 2020. The World Bank Indicators. World Bank, Washington, DC. URL. https://data.worldbank.org/. URL December 2020.

Ben-Salha, O., Dachraoui, H., Sebri, M., 2018. Natural resource rents and economic growth in the top resource-abundant countries: a PMG estimation. Res. Pol. 101229 https://doi.org/10.1016/j.resourpol.2018.07.005.

Bildirici, M.E., Gokmenoglu, S.M., 2019. Does restource curse really exist in precious metal producer countries? Nat. Resour. Res. 28, 1403–1428. https://doi.org/10.1007/s11053-019-09468-7.

Bildirici, M.E., Turkmen, C., 2015. Nonlinear causality between oil and precious metals. Res. Pol. 46, 202–211. https://doi.org/10.1016/j.resourpol.2015.09.002.

Bolch, K.B., Ceriani, L., López-Calva, L.F., 2022. The arithmetics and politics of domestic resource mobilization for poverty eradication. World Dev. 149, 105691.

Börzel, T., Hönke, J., 2010. From compliance to practice: mining companies and the voluntary principles on security and human rights in the Democratic Republic of Congo. In: APSA 2010 Annual Meeting Paper.

Boschini, A.D., Pettersson, J., Roine, J., 2007. Resource curse or not: a question of appropriability. Scand. J. Econ. 109, 593–617. https://doi.org/10.1111/j.1467-9442.2007.00509.x.

Broock, W.A., Scheinkman, J.A., Dechert, W.D., LeBaron, B., 1996. A test for independence based on the correlation dimension. Econom. Rev. 15, 197–235.

Calvão, F., Mcdonald, C.E.A., Bolay, M., 2021. Cobalt mining and the corporate outsourcing of responsibility in the Democratic Republic of Congo. Extr. Ind. Soc.

Caramento, A., Messages, K., 2020. Trends in Extraction of Mineral Resources in East and Southern Africa Alex Caramento , for the Regional Network for Equity in Health in East, pp. 1–20.

Crowson, P., 2012. Some observations on copper yields and ore grades. Res. Pol. 37, 59–72. https://doi.org/10.1016/j.resourpol.2011.12.004.

Department, U. state, 2017. Conflit Minerals.

Doucouliagos, H., Paldam, M., 2009. The aid effectiveness literature: the sad results of 40 years of research. J. Econ. Surv. 23, 433–461.

Douglas, P.H., 1976. The Cobb-Douglas production function once again: its history, its testing, and some new empirical values. J. Polit. Econ. 84, 903–915.

Enders, W., 2015. Applied Econometric Time Series, 4 th. John Wiley & Sons.

Fernandez, V., 2014. Linear and non-linear causality between price indices and commodity prices. Res. Pol. 41, 40–51.

Frankel, J., 2011. 1. The Natural Resource Curse: A Survey. University of Pennsylvania Press.

Frankel, J.A., 2012. The natural resource curse: a survey of diagnoses and some prescriptions. HKS Fac. Res. Work. Pap. Ser.

Ghosh, S., 2006. Steel consumption and economic growth: evidence from India. Res. Pol. 31, 7–11.

Haber, S., Menaldo, V., 2011. Do natural resources fuel authoritarianism? A reappraisal of the resource curse. Am. Polit. Sci. Rev. 105, 1–26.

Hamdi, H., Sbia, R., 2013. Dynamic relationships between oil revenues, government spending and economic growth in an oil-dependent economy. Econ. Modell. 35, 118–125. https://doi.org/10.1016/j.econmod.2013.06.043.

Harris, R.I.D., 1992. Testing for unit roots using the augmented Dickey-Fuller test: some issues relating to the size, power and the lag structure of the test. Econ. Lett. 38, 381–386.

Hatemi-j, A., 2012. Asymmetric causality tests with an application. Empir. Econ. 43, 447–456.

Hatemi-J, A., 2012. Asymmetric causality tests with an application. Empir. Econ. 43, 447–456. https://doi.org/10.1007/s00181-011-0484-x.

Havranek, T., Horvath, R., Zeynalov, A., 2016. Natural resources and economic growth: a meta-analysis. World Dev. 88, 134–151.

Hiemstra, C., Jones, J.D., 1994. Testing for linear and nonlinear Granger causality in the stock price-volume relation. J. Finance 49, 1639–1664.

Institute, C., n.d, 2017. Cobalt Uses.

Institute, T.F., 2021. Faraday Insights. U.K.

Jaunky, V.C., 2013. A cointegration and causality analysis of copper consumption and economic growth in rich countries. Res. Pol. 38, 628–639. https://doi.org/10.1016/j.resourpol.2013.10.001.

Jaunky, V.C., 2012. Aluminum consumption and economic growth: evidence from rich countries. Nat. Resour. Res. 21, 265–278. https://doi.org/10.1007/s11053-012-9171-7.

Johansen, S., 1992. Determination of cointegration rank in the presence of a linear trend. Oxf. Bull. Econ. Stat. 54, 383–397.

Kapetanios, G., Shin, Y., Snell, A., 2003. Testing for a unit root in the nonlinear STAR framework. J. Econom. 112, 359–379.

Karl, T.L., 1997. The Paradox of Plenty: Oil Booms and Petro-States. Univ of California Press.

Katz-Lavigne, S., 2019. Artisanal copper mining and conflict at the intersection of property rights and corporate strategies in the Democratic Republic of Congo. Extr. Ind. Soc. 6, 399–406.

Kim, D., Perron, P., 2009. Unit root tests allowing for a break in the trend function at an unknown time under both the null and alternative hypotheses. J. Econom. 148, 1–13.

Kwiatkowski, D., Phillips, P.C.B., Schmidt, P., Shin, Y., 1992a. Testing the null hypothesis of stationarity against the alternative of a unit root: how sure are we that economic time series have a unit root? J. Econom. 54, 159–178.

Kwiatkowski, D., Phillips, P.C.B., Schmidt, P., Shin, Y., 1992b. Testing the null hypothesis of stationarity against the alternative of a unit root. J. Econom. 54, 159–178.

Kyrtsou, C., Labys, W.C., 2006. Evidence for chaotic dependence between US inflation and commodity prices. J. Macroecon. 28, 256–266. https://doi.org/10.1016/j.jmacro.2005.10.019.

Labson, B.S., Crompton, P.L., 1993. Common trends in economic activity and metals demand: cointegration and the intensity of use debate. J. Environ. Econ. Manag. 25, 147–161.

Lanne, M., Nyberg, H., 2016. Generalized forecast error variance decomposition for linear and nonlinear multivariate models. Oxf. Bull. Econ. Stat. 78, 595–603. https://doi.org/10.1111/obes.12125.

Li, Z. Bin, Deng, H.J., Cheng, A.S., 2013. The study of the relationship between natural resource abundance and economic growth. In: Advanced Materials Research. Trans Tech Publ, pp. 3337–3341.

Li, L., Pan, D., Li, B., Wu, Y., Wang, H., Gu, Y., Zuo, T., 2017. Patterns and challenges in the copper industry in China. Resour. Conserv. Recycl. 127, 1–7.

Linnecke, C.M., 2016. Evaluating conflict mineral legislation in the democratic republic of Congo. Proc. Gt. Day 60.

Nkulu, C.B.L., Casas, L., Haufroid, V., De Putter, T., Saenen, N.D., Kayembe-Kitenge, T., Obadia, P.M., Mukoma, D.K.W., Ilunga, J.-M.L., Nawrot, T.S., 2018. Sustainability of artisanal mining of cobalt in DR Congo. Nat. Sustain. 1, 495–504.

Ober, J.A., 2016. Mineral Commodity Summaries 2016. Mineral Commodity Summaries, Reston, VA. https://doi.org/10.3133/70170140.

Perron, P., 1989. The great crash, the oil price shock, and the unit root hypothesis. Econom. J. Econom. Soc. 1361–1401.

Pourret, O., Lange, B., Houben, D., Colinet, G., Shutcha, M., Faucon, M.-P., 2015. Modeling of cobalt and copper speciation in metalliferous soils from Katanga (Democratic Republic of Congo). J. Geochem. Explor. 149, 87–96. https://doi.org/10.1016/j.gexplo.2014.11.011.

Roberts, M.C., 1996. Metal use and the world economy. Res. Pol. 22, 183–196.

Satti, S.L., Farooq, A., Loganathan, N., Shahbaz, M., 2014. Empirical evidence on the resource curse hypothesis in oil abundant economy. Econ. Modell. 42, 421–429. https://doi.org/10.1016/j.econmod.2014.07.020.

Shengo, M.L., Kime, M.-B., Mambwe, M.P., Nyembo, T.K., 2019. A review of the beneficiation of copper-cobalt-bearing minerals in the Democratic Republic of Congo. J. Sustain. Min. 18, 226–246.

Shin, Y., Yu, B., Greenwood-Nimmo, M., 2014. Modelling asymmetric cointegration and dynamic multipliers in a nonlinear ARDL framework. In: Festschrift in Honor of Peter Schmidt. Springer, pp. 281–314.

Te, 2021. Trading econimcs [WWW Document]. URL. https://tradingeconomics.com/copperprice. (Accessed 20 September 2020).

Tilton, J.E., 1989. The new view of minerals and economic growth. Econ. Rec. 65, 265–278. https://doi.org/10.1111/j.1475-4932.1989.tb00935.x.

Toda, H.Y., Yamamoto, T., 1995. Statistical inference in vector autoregressions with possibly integrated processes. J. Econom. 66, 225–250.

USGS, 2020a. USGS science for a changing World [WWW Document]. URL. https://www.usgs.gov/centers/nmic/copper-production. (Accessed 21 September 2020).

USGS, 2020b. Geological survey, mineral commodity summaries. U.S. geological survey. https://doi.org/10.3133/mcs2020.

Weber, J.G., 2012. The effects of a natural gas boom on employment and income in Colorado, Texas, and Wyoming. Energy Econ. 34, 1580–1588. https://doi.org/10.1016/j.eneco.2011.11.013.

Williams, A., 2011. Shining a light on the resource curse: an empirical analysis of the relationship between natural resources, transparency, and economic growth. World Dev. 39, 490–505.

World Bank Group, 2015. World Bank - List of Economies, pp. 1–7.