Resources Policy 78 (2022) 102843

Contents lists available at ScienceDirect

Resources Policy

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

# An empirical investigation of resource curse hypothesis for cobalt

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ARTICLE INFO

*Keywords:*
Resource curse
Cobalt
Economic growth
Second-generation panel tests

ABSTRACT

Natural resources are considered as one of the most important factors stimulating the economic growth and development of countries. The studies concerning the relationship between the abundance of resources and economic growth, namely the resource curse, are increasing day by day and have produced conflicting results, either accepting, rejecting, or partially accepting the existence of the curse. Since the last decade, cobalt chemicals demand has radically increased because of the usage of Li-ion batteries in consumer electronics and electric vehicles. Due to the increasing importance of cobalt as a resource, this study takes an attempt to explore the resource curse hypothesis for cobalt for Australia, Canada, the Democratic Republic of Congo, Cuba, Morocco, Russia, and South Africa over the period of 2000–2018. The study employs second-generation panel data techniques in order to account for the dependency in the cross-sectional units and parameter heterogeneity. The findings of the study show that while the Democratic Republic of Congo exhibits evidence of the resource curse hypothesis for cobalt resource abundance, Canada, Cuba, and Russia reveal a positive relationship between economic growth and cobalt resource availability. For the whole panel, this study fails to find any evidence of the resource curse hypothesis in terms of Cobalt. Based on the findings, several policy implications are provided.

## 1. Introduction

There have been a significant amount of studies done on the relationship between natural resources and economic growth, trying to confirm whether countries that are rich in resources are outperformed by those who are poor in terms of the growth of their economy. When countries that are poor in resources outperform those that are rich in these resources, the phenomenon is known as the resource curse theory in the empirical literature. The number of papers investigating the curse has increased after the seminal studies of Sachs and Warner (1995 and 1997). The first studies examining the conceptual framework behind the resource curse are Gelb (1988) and Auty (1990). Following these studies, the pioneering studies by Sachs and Warner (1995 and 1997) compare Asian Tigers and oil-rich countries such as Mexico, Venezuela, and Nigeria. They assert that while oil-rich countries were experiencing bankruptcies, newly industrialized, resource-poor East Asian countries were experiencing an uninterrupted growth pattern. Hence, they state that resource abundance poses a quite ironic role in causing negative or slow economic growth. The above phenomenon is best explained by the Dutch disease. In this case, resources are reallocated from the manufacturing sector to the primary commodity, and as a result, both the external sector as well as domestic economy get affected. The external sector gets affected because the exports of manufacturing become less and less competitive when the exchange rate starts to appreciate. The above hypothesis behind the resource curse theory is known as Dutch disease (Williams, 2011).

The phenomenon of economic growth has been one of the leading research fields of economics and has attracted the attention of many researchers and policymakers alike. Numerous studies have been conducted to find the factors causing economic growth in different contexts and countries. Considering that raw materials are an indispensable part of the production, it would not be wrong to argue that economic growth comes from having raw materials. In this study, the relationship between raw materials and economic growth will be examined for cobalt metal in the framework of the "resource curse" theory. Cobalt is a crucial mineral, especially for electric cars' and cell phones' batteries, superalloys, and it is critical for renewable energy transition since it enables renewable energy storage. In addition to this, substitution from using cobalt is practically inapplicable due to increasing costs and product performance losses. In that sense, cobalt usage is inevitable under

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https://doi.org/10.1016/j.resourpol.2022.102843
Received 16 April 2022; Received in revised form 10 June 2022; Accepted 10 June 2022
Available online 18 June 2022
0301-4207/

known technologies.

When the cobalt market is examined from the demand side, it can be stated that as the governments continue to encourage greener and more sustainable energy production and transportation vehicles, the demand for cobalt-used batteries will continue to increase. In other words, due to the acceleration of the low carbon transition, especially in Europe, substantial changes in transportation vehicles and power generating sectors will increase. The use of electric vehicles (EV) and renewable-based electricity production have increased. The battery market developments, due to the increasing demand for greener energy, and the increasing use of personal electronics and EVs, are expected to boost the raw material demand, especially in the cobalt market. China's "Made in China (2025)" (MIC2025) strategy, which focuses on improving technology and supporting the development of selected ten advanced Chinese industries, is also causing cobalt need or dependency hike.

Now, if we consider the supply side of the cobalt market, the market seems to be highly concentrated. Cobalt can be found in less than twenty countries, and the major supplier of cobalt is the Democratic Republic of Congo (DRC hereafter). Approximately 70% of the cobalt production comes from DRC, and nearly 30% percent of this production come from artisanal small-scale mines. Moreover, the top five cobalt producer firms control nearly 53% of the global supply. Interestingly, China is the prominent player in the global cobalt refinery industry in order to secure raw cobalt materials required for manufacturing.

There are several issues that need to be mentioned while talking about the global cobalt supply. First of all, cobalt is produced as a byproduct of other metals, so the supply is mainly dependent on these metals' demand and extraction capacities. Secondly, DRC production is highly reliant on artisanal mines, which raises several ethical questions on child labor or low wage levels besides supply sustainability. Thirdly, since DRC is usually experiencing problems such as political instability, war, coup, corruption, etc., the cobalt supply is also experiencing supply volatility, hence price volatility. Under the terms of the abovementioned clauses, it can be stated that the relationship between cobalt endowments and economic growth will become one of the primary concerns for policymakers in the upcoming decades. Numerous studies examine the resource curse, but the number of papers concerning the relationship between cobalt resource abundance and economic growth is limited. In other words, although cobalt metal is gaining strategic importance, the macroeconomic impacts associated with supplying this raw material remain unexplored and robust analysis supported with empirical evidence is required.

The contribution of this study comes from several aspects. First of all, this study analyzes whether cobalt suppliers experience a resource curse or not by adopting a Cobb-Douglas function approach. Secondly, the study uses cobalt market value which is calculated via the multiplication of cobalt supply and prevailing market price. Hence, the study is not only considering the cobalt endowments but also the associated market impacts via cobalt price. Thirdly, we use second-generation panel data techniques which are robust across cross-sectional dependence. Specifically, we apply several cross-sectional dependence tests, CIPS panel unit root test, Durbin-H Panel Cointegration Test, Augmented Mean group estimation, and Emirmahmutoglu- Kose Panel Causality Test to provide robust evidence of the resource curse hypothesis in terms of cobalt. Lastly, we examine the cobalt curse hypothesis for the largest producers of cobalt. Although there are numerous studies in the literature aiming to investigate the resource curse for several other oil and non-oil resources, to the best of our knowledge, no studies have yet investigated how the presence of cobalt in an economy can lead to its underperformance in terms of growth. This study uses the total market value of cobalt (COB), real capital use per capita (CAP), total labor force per capita (LAB), and GDP per capita (GDP) and investigates the relationship between economic growth and cobalt resource endowment in the context of resource curse for Australia, Canada, DRC, Cuba, Morocco, Russia, and South Africa between 2000 and 2018. These countries are the biggest suppliers of cobalt with different levels of development; hence our results will be crucial for revealing the opportunities and risks associated with the proposed boom in their cobalt supply.

The study is comprised of six sections; the subsequent section aims to give a key insight into the global market structure of cobalt. The next section is the literature part. The econometric methodology and the data used in this study are explained in the fourth section. Following the econometric results and discussions, the sixth part will conclude the study.

## 2. An insight into the global cobalt economy

Cobalt is a ferromagnetic metal found on the Earth naturally associated with nickel and copper. It is usually acquired via copper and nickel mining as a byproduct (Tisserant and Pauliuk, 2016). For a long time in history -nearly since Bronze Age-, cobalt-based coloring has been used in jewelry making, pottery, and glass painting.

The global cobalt market demand can be divided into two subcategories of products: cobalt metal and cobalt chemicals (Fig. 1). Cobalt metal is primarily used in the manufacturing and aerospace sectors for making stainless steel, high-temperature resistant superalloys, cutting tools, automotive and industrial equipment, implants, etc. It is sold on London Metal Exchange mostly in an ingot form.

Previously metallic cobalt dominated the global market, but the overwhelming technological developments in the last decade have changed this pattern. With green recovery policies and other incentives, EV demand increased sharply; at the same time, the widespread of 5G technology supported the demand for personal portable electronics. Due to the increased uptake of consumer electronics and developments in EV technologies, cobalt chemicals' demand is expected to rise. As shown in Fig. 2, according to CRU Group (a company founded in 1969 and specializes in global mining and metals), the demand for cobalt chemicals is expected to be two-thirds of the global cobalt demand by 2026 (see Fig. 2).

As can be seen in Fig. 3, geographically, Asian countries alone accounted for nearly half of cobalt consumption. China is the largest consuming country as a hub for battery manufacturing. The other important centers in Asia are Japan and South Korea. Europe and North America together consume nearly 40% of the total consumption.

According to USGS Mineral Commodity Summary Report (USGS, 2020), the use of cobalt substitutes can cause a loss in end-product performance or result in cost hikes; hence it is very important to maintain stability of supply. Cobalt metal market supply exhibits high market concentration in terms of supplier countries. As DRC has nearly half of the cobalt reserves, it has a dominating role in the market, followed by Australia, Canada, Russia, and Cuba (USGS, 2020). On the other hand, most of the cobalt chemicals are processed in China via cobalt metal imported from the DRC.

The World cobalt mine production and cobalt prices from 1968 to 2017 are given in the figure below.

Fig. 4 shows that there has been a persistent increase in the production of cobalt, especially after 1994. Besides supply structure, when the price trend of cobalt over time is examined, one can see that the price exhibits an upward trend and is highly volatile. This volatility can be caused by supply constraints, technological changes, or increasing demand.

Table 1 exhibits the amount of cobalt production and the total amount of known reserves on the basis of countries. As it can be seen from the table, the DRC dominates the market while having nearly half of the known reserves; it is also responsible for two-thirds of the total production.

## 3. Literature survey

Compared to their fossil fuel counterparts, renewable energy technologies are considered to be in need of more and different materials. In the near future, it is expected that consumption of metals will increase

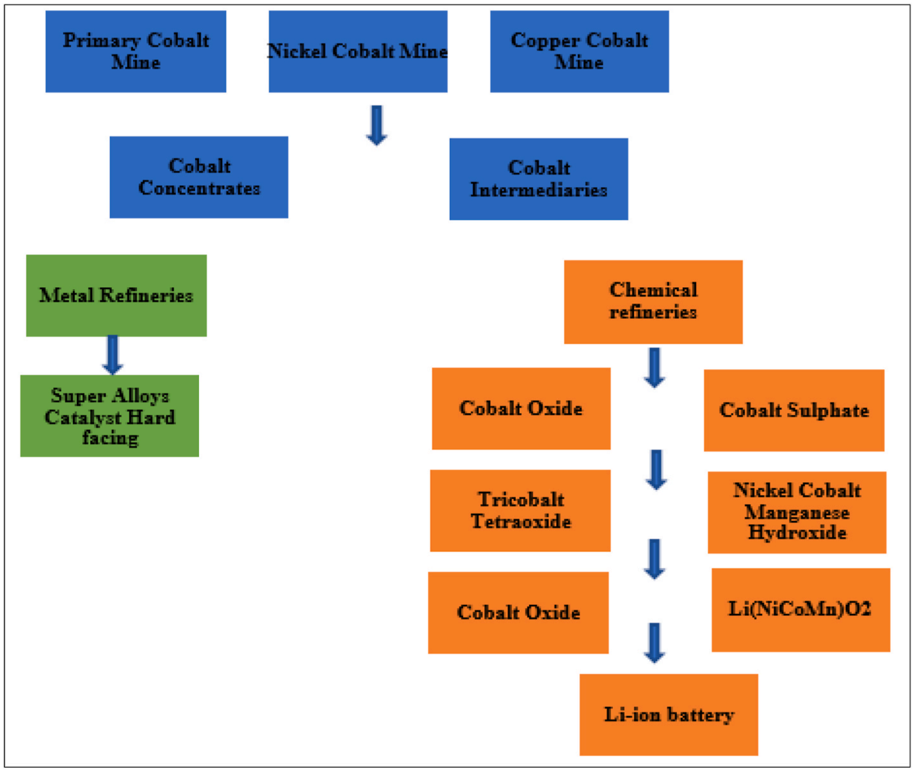


**Fig. 1.** Global cobalt industry Chain
Source: Leighton, M. 2021.

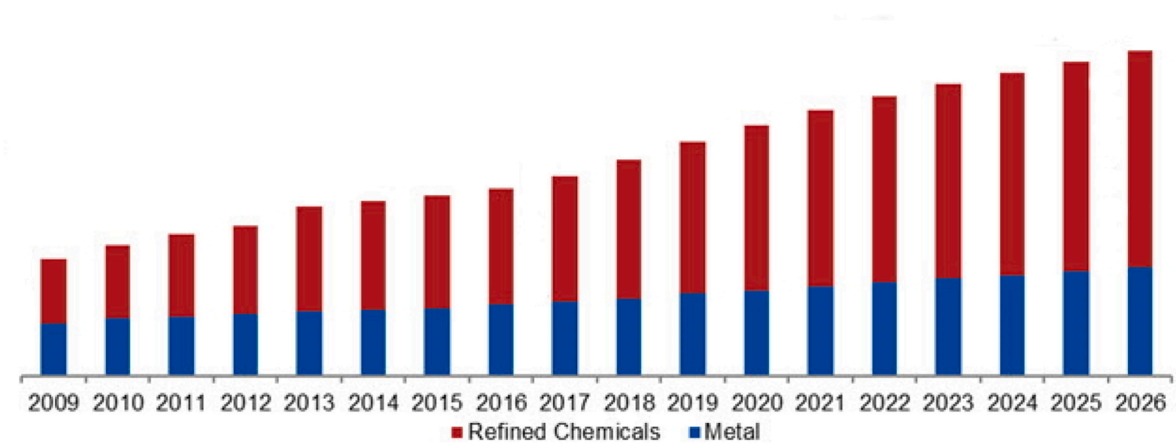


**Fig. 2.** The demand for Cobalt
Source:CRU Group, 2017.

significantly, and technologies related to low carbon will be the pioneer in increasing that demand. Specifically, the demand for cobalt is increasingly growing (Månberger, 2021). A country's economic development and abundance of resources linkage can be examined through the lens of resource curse theory. On the one hand, resources provide avenues of growth and investment via increased revenues. However, there are several reasons why resource abundance may lead to economic development that is poor. These reasons may include a drop in prices of global commodities, uncertainty, unstable earnings for countries that export resources, and crowding-out effects (Matti, 2010).

In a study on precious metal countries, Bildirici and Gokmenoglu (2019) examined how the production of precious metal and economic growth is related. They used seven countries, and their study period considered 1963 to 2016 annual data. Utilizing the Markov switching vector error correcting model, they found that the impacts of these metals on growth differed. There was a long-run association between growth and metals. In terms of gold and copper production, the findings suggested evidence of the resource curse for the USA and Canada but not that of South Africa in the short run. In South Africa, both silver and copper production had a positive impact on economic growth. There was also evidence of Peru's resource curse in terms of copper production.

In a seminal study, Smith (2015) analyzed the resource curse theory in several countries using robust models. He used recent discoveries in the period of post-colonial to examine the association between growth and resource. A major contribution of this study was that it used a quasi-experimental, treatment-control approach to explore this case which is much more robust compared to other countries. He found that

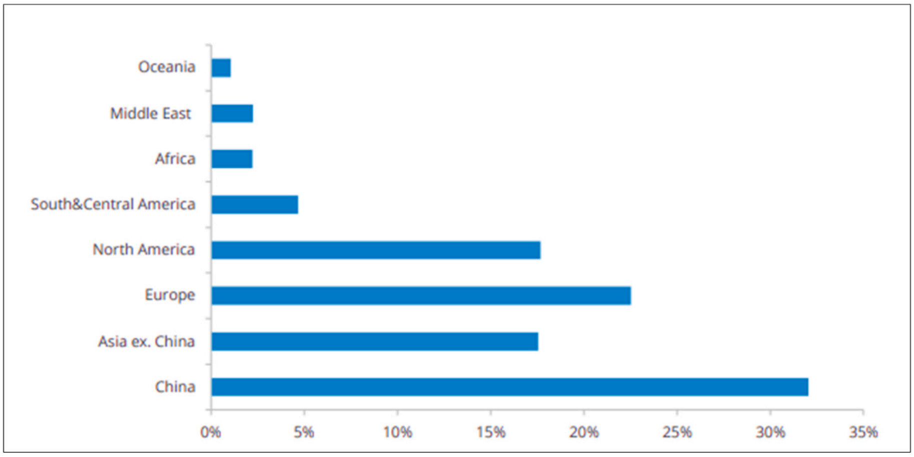


**Fig. 3.** The Consumption of Cobalt by Region (2020)
Source: Cobalt Institute, 2021: p.8.

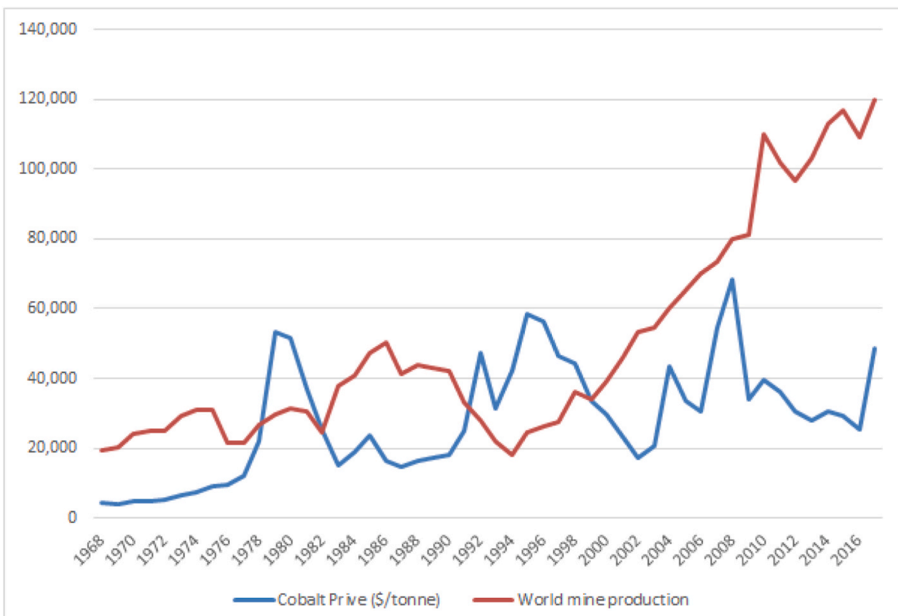


**Fig. 4.** Cobalt price and Production
Source: USGS, 2018.

**Table 1**
World cobalt production and reserves.

| | Production | | Reserves |
|---|---|---|---|
| | 2019 | 2020 | |
| **DRC** | 100,000 | 95,000 | 3,600,000 |
| **Russia** | 6300 | 6300 | 250,000 |
| **Australia** | 5740 | 5700 | 1,400,000 |
| **Philippines** | 5100 | 4700 | 260,000 |
| **Cuba** | 3800 | 3600 | 500,000 |
| **Canada** | 3340 | 3200 | 220,000 |
| **Papua New Guinea** | 2910 | 2800 | 51,000 |
| **China** | 2500 | 2300 | 80,000 |
| **Morocco** | 2300 | 1900 | 14,000 |
| **South Africa** | 2100 | 1800 | 40,000 |
| **Other** | 10,220 | 11,700 | 713,000 |
| **Total** | **144,000** | **140,000** | **7,100,000** |

Source: USGS, 2021

in the developing countries, there is evidence of the resource curse in the long term, while developed countries did not suffer from this effect.

Hussain et al. (2020) studied four countries such as Brazil, Russia, China, and India, to examine how their resource endowment can affect the countries' financial development and thus provided an analysis of the resource curse theory. They employed robust second-generation econometric techniques. The result from CS-ARDL revealed that natural resource rent is positively associated with financial development in these four countries both in the short and long-run. The results of the CCEMG model also supported this fact.

For the next 11 countries, Rahim et al. (2021) explored the possibility of the resource curse by taking 30 years period data. Furthermore, they explored human capital's indirect effect on growth. They found evidence of the resource curse for these eleven countries while they also discovered a significant positive impact of human capital in direct and indirect ways. They summarized that utilization, as well as extraction of these countries' natural resources, depend critically on the development of human capital, which can improve their growth trajectories. So if policies are appropriate in developing human capital, they can convert this curse into a blessing.

While most of the previous studies have examined the country or panel studies for the resource curse hypothesis, Fleming et al. (2015) utilized within-country data to examine this case for Australia. Specifically, they wanted to see if the curse holds for regions that surround mining operations. They utilized both traditional and spatial econometric tools and employed 449 nonmetropolitan local government areas. Although not always, resource windfalls were discovered to be a blessing for Australian regions. But for the eastern part of the country, mining expansions did not increase economic growth when non-mining employment is considered. They concluded that there might be a lack of strategic planning, which is why the regional resource curse might exist in several regions.

In another study, Dwumfour and Ntow-Gyamfi (2018) examined the effect of resource rents on the financial development of African countries. They utilized 38 countries and divided them into different categories, and employed the GMM approach for proving their claims. For these categories, they found mixed results. The result revealed the curse for low, and middle income as well as for Sub-Saharan Africa. But they did not find any evidence for this hypothesis in the region of North Africa. They also provided evidence that the quality of institutions can decrease the impact of the rent on the financial development variable.

Utilizing more than 40 years of data, Haseeb et al. (2021) examined how resources and economic growth are related in top countries of Asia. They utilized five countries in Asia and employed Quantile on Quantile regression. For the four countries, they found no possibility of the resource curse while the Indian economy suffered from this curse. They recommended that in extracting resources, efficiency can be improved by utilizing innovations and improved technology which can save waste and leakages. To preserve these resources, there is also a need for an improved system of government.

Similar to the Australian study of Fleming et al. (2015), Alexeev and Chernyavskiy (2014) examined how economic growth and resources are associated in Russian regions. They found evidence that resource rents in terms of mineral wealth had no significant impact on the economic growth of regions since 2002. But they found that regions that are rich in minerals are comparatively richer. They concluded that their results contradicted the resource curse hypothesis. They utilized several variables for measuring resources, such as extractive industries and revenues from the tax on extracting mineral resources. They said this result could be due to the fact that in the 2000s, the central government in this country taxed away from the regional resource rents.

## 4. Data and methodology

### 4.1. Data description

In this study, we analyze the effect of cobalt production on the economic growth of Australia, Canada, Congo, Cuba, Morocco, the Russian Federation, and South Africa from 2000 to 2018. We select these countries because they produce about 88.4% of cobalt production in the world.[1]

We employ the following augmented production model in this study:

$$LnGDP_{it} = \beta_1 + \beta_2 LnCOB_{it} + \beta_3 LnK_{it} + \beta_4 LnL_{it} + e_{it}$$

Where $GDP_{it}$ shows the gross domestic product (GDP) per capita (constant 2010 US$), $COB_{it}$ is the value of the cobalt mine production of the considered country, $K_{it}$ indicates gross fixed capital formation (constant 2010 US$), and $L_{it}$ is total labor force. To obtain $COB_{it}$, we first product the cobalt production with the cobalt price, deflate with the GDP deflator (constant 2010) of the considered country and divide with the population to reduce the disparities among the countries. We use all variables in logarithm forms. We obtain cobalt production and cobalt price from the British Petroleum Statistical Review of World Energy and the remaining data are from the World Bank.

### 4.2. Methodology

#### 4.2.1. Cross-sectional dependence tests

Cross-sectional dependence, which is described as the interaction between the cross-sections of a panel, is usually attributed to the effect of unknown common shocks, interactions within social networks, or spatial dependence (De Hoyos and Sarafidis, 2006; Baltagi et al., 2012; Baltagi et al., 2016). One should test the existence of cross-sectional dependence among the panel members before performing an econometric technique to avoid inconclusive inferences.

To test the null hypothesis of no-cross dependence against the alternative of the presence of the cross-sectional dependence, we will employ Breusch-Pagan Lagrange Multiplier ($LM_{BP}$), Pesaran scaled LM ($LM_{BC}$), and Bias-corrected scaled LM (CD) tests in this study. $LM_{BP}$ test is valid unless $N \to \infty$, and one can use the following formulae to compute the $LM_{BP}$ test statistic:

$$LM_{BP} = T \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \breve{\rho}_{ij}$$

Where $T$ and n shows the time and cross-section dimension of the panel data. $\breve{\rho}_{ij}$ is the sample correlation coefficient of the errors ($u_{it} = y_{it} - \widehat{\alpha}_i - \widehat{\widehat{\beta}}_i x_{it}$) that is given by

$$\breve{\rho}_{ij} = \breve{\rho}_{ji} = \left(\sum_{t=1}^{T} u_{it}^2\right)^{-1/2} \left(\sum_{t=1}^{T} u_{jt}^2\right)^{-1/2} \sum_{t=1}^{T} u_{it} u_{jt}$$

$LM_{BP}$ is distributed as chi-squared with $N(N-1)/2$ degrees of freedom. To remedy the shortcoming of the BPLM test, Pesaran (2004) standardized the $LM_{BP}$ test by defining the new test statistic as

$$CD = \sqrt{\frac{2T}{N(N-1)}} \left( \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \breve{\rho}_{ij} \right)$$

The *CD* test statistic is asymptotically distributed as normal with $T \to \infty$ and $N \to \infty$. Pesaran (2004) notes that the CD test will exhibit substantial size distortions when the distribution of the errors is not symmetric. Baltagi et al. (2012) proposed to correct the asymptotic deviations of the Pesaran (2004)'s LM test using the following test statistic:

$$LM_{BC} = \sqrt{\frac{1}{N(N-1)}} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \left( T_{ij} \breve{\rho}_{ij}^2 - 1 \right) - \frac{1}{2(T-1)}$$

$LM_{BC}$ is normally distributed.

#### 4.2.2. CIPS panel unit root test

Since the last decade, there has been a growing literature on considering cross-sectional dependence among the panel members since ignoring dependence bias the size of tests based on the estimation panel regression models as noted by Baltagi et al. (2007). So, to allow for such dependence in unit root testing, we will employ the cross-sectionally augmented IPS (CIPS) panel unit root test of Pesaran (2007) that is based on the individual cross-sectional augmented Dickey-Fuller (CADF) unit root test.

One can obtain the CADF test statistic by estimating the following test regression:

$$\Delta X_{i,t} = \alpha_i + \beta_i X_{i,t-1} + \gamma_i \overline{X}_{t-1} + \sum_{j=0}^{p} \delta_{i,j} \Delta \overline{X}_{t-j} + \sum_{j=1}^{p} \varepsilon_{i,j} \Delta X_{i,t-j} + u_{i,t}$$

[1] Besides, there is no available data for the remaining countries.

Where Δ and over-bars indicate the first differences and averages of the considered variable. We can obtain the CADF test statistic to test the null hypothesis of a unit root for the individual $i$ as follows:

$$CADF_i = \frac{\Delta X_i' \overline{M}_Z X_{i,-1}}{\widehat{\sigma}_i \sqrt{\left(X_{i,-1}' \overline{M}_Z X_{i,-1}\right)}}$$

Where $\overline{M}_Z = I_T - \overline{Z}(\overline{Z}'\overline{Z})^{-1}\overline{Z}'$, $\overline{Z} = (\tau, \Delta\overline{X}, \overline{X}_{-1})$, $\tau = (1,1,1,...,1)'$, $\widehat{\sigma}_i^2 = (T-4)^{-1}(\Delta X_i' M_{i,Z} \Delta X_i)$, $M_{i,Z} = I_T - G_i(G_i' G_i)^{-1}$, and $G_i = (\overline{Z}, X_{i,-1})$.

To compute the CIPS test statistic, we can compute the average of the CADF test statistics of all members of the panel as follows:

$$CIPS = N^{-1} \sum_{i=1}^{N} CADF_i$$

By employing the CIPS test statistic, the null of unit root for all-time series in the panel can be tested against the alternative of at least one member of the panel being stationary. Pesaran (2007) tabulated the necessary critical values for the CIPS test.

#### 4.2.3. Durbin- H panel cointegration test

Ignoring cross-sectional dependence also may lead to invalid conclusions in panel cointegration tests. So, in this study, we investigate the existence of a long-run relationship between the variables, employing the Durbin-H panel cointegration test that is introduced by Westerlund (2008). This test not only considers cross-sectional dependence among the panel members but also allows regressors to be either I(0) or I(1).

One should estimate the following equation to obtain the Durbin-H test statistic:

$$Y_{it} = a_i + b_i X_{it} + \varepsilon_{it}$$

$\varepsilon_{it}$ supposed to fulfill the following conditions to consider cross-sectional dependence:

$$\varepsilon_{it} = \lambda_i' F_t + e_{it}$$

$$F_{jt} = \rho_j F_{jt-1} + u_{jt}$$

$$e_{it} = \theta_i e_{it-1} + v_{it} \quad (1)$$

Where $F_t$ shows an m-dimensional vector of common factors $F_{jt}$ with $j = 1,2,3,...,m$ and $\lambda_i$ is a vector of factor loadings. To ensure $F_t$ is stationary, $\rho_j$ is assumed to be less than 1 for all j. We reject the null of no-cointegration if $\theta_i < 1$ in (1). Westerlund (2008) proposes two test statistics; $DH_p$ and $DH_g$. While the former assumes homogeneity, the latter assumes heterogeneity under the alternative hypothesis. Durbin-h panel test is asymptotically distributed as normal.

#### 4.2.4. Augmented Mean Group

This study estimates the long-run coefficients via a technique called Augmented Mean Group (AMG). According to Chopra et al. (2022), the first-generation panel techniques are not efficient when the data exhibits signs of cross-sectional dependency. This method can take into account any dependence between the cross-sectional units and also the heterogeneity, which can be country-specific. This is done so that over-generalization can be avoided. Moreover, when we have variables that are not stationary, this method can be employed since it is very flexible (Nathaniel et al., 2020a, 2020b). The method was primarily developed by Bond and Eberhardt (2009) and Eberhardt and Teal (2010).

#### 4.2.5. Emirmahmutoglu- Kose Panel Causality Test

One should difference the data if it is non-stationary to use the panel Dumitrescu and Hurlin (2012) causality test, which is based on the individual Granger causality tests. However, Toda and Yamamoto (1995) introduce a new causality test by augmenting the vector autoregressive model with an extra lag equal to the maximal integration order of the interested variables. Emirmahmutoglu and Kose (2011) (EK) follow the Fisher's (1932) meta-analysis suggestion and propose a new panel causality test that is based on the individual Toda and Yamamoto (1995) causality test statistics. We can estimate the following lag-augmented vector autoregressive model to apply the Toda-Yamamoto causality test:

$$W_{i,t} = \mu_i + A_{i1} W_{i,t-1} + ... + A_{ik} W_{i,t-k_i} + \sum_{l=k_i+1}^{k_i+d\max_i} A_{il} W_{i,t-l} + u_{i,t},\ i = 1,2,3,...,N,\ t = 1,2,3,...,T$$

Where $d_{\max_i}$ shows the maximal integration order of the $i$ th individual. $W_{i,t} = (Y_{i,t}, X_{i,t})'$ and $A_{ij} = \begin{bmatrix} A_{11,ij} & A_{12,ij} \\ A_{21,ij} & A_{22,ij} \end{bmatrix}$ for $j = 1,2,...,k$. We can conclude that $X_{i,t}$ does not Granger cause $Y_{i,t}$ when $A_{12,ij} = 0$. The individual Wald test statistics to test the null hypothesis is distributed as chi-square. By following Fisher (1932) suggestion, Emirmahmutoglu and Kose (2011) propose the combine the p-values of the individual Wald test statistics to obtain panel causality test (panel EK) statistics to test the null hypothesis of Granger non-causality as:

$$EK = -2\sum_{i=1}^{N} \ln(p_i)\ i = 1,2,3,...,N$$

EK suggest obtaining the necessary critical values by using bootstrap simulations to consider cross-sectional dependency.

## 5. Empirical results and discussion

As the first step of empirical application, we tested the existence of cross-sectional dependence among the panel members and presented the test results in Table 2:

We can conclude that the cross-sectional dependence exists for all the considered variables, so second-generational panel techniques should be used that allow this dependence. At the next step of the analysis, we test the unit root characteristics of the variables using the CIPS panel unit root test. Table 3 illustrates the results:

The results of the CIPS panel unit root test indicate that LnCOB and LnGDP are stationary at the first difference while LnK and LnL are stationary at the level. Since these findings meet the requirement of the Durbin-H panel cointegration test, next, we apply the test and tabulate the results in Table 4.

The output in Table 4 provides strong evidence of the long-run relationship among the variables. To estimate the long-run coefficients, we use the panel AMG estimation technique that allows cross-sectional dependence. We provide the results in Table 5.

The coefficient of cobalt is positive but insignificant for Australia. This matches with the result of Bildirici and Gokmenoglu (2019), who found no significant impact of silver on economic growth for Australia. The positive result also matches with Fleming et al. (2015), who found evidence that resources are a blessing for most of the regions in Australia. In terms of capital and labor, they are both found to be insignificant for this country, although the effect of labor is higher compared to the other two variables. An interesting result seems to emerge in the coefficient of LnCOB of Congo, which is the largest producer of cobalt in the world. An increase in LnCOB decreases the LnGDP

**Table 2**
Results of cross-sectional dependence tests.

| Variables | $LM_{BP}$ | $CD$ | $LM_{BC}$ |
|---|---|---|---|
| LnCob | 104.597 (0.000)* | 12.899 (0.000)* | 12.705 (0.000)* |
| LnGDP | 362.621 (0.000)* | 52.713 (0.000)* | 52.519 (0.000)* |
| LnK | 323.076 (0.000)* | 46.611 (0.000)* | 46.417 (0.000)* |
| LnL | 170.645 (0.000)* | 23.091 (0.000)* | 22.896 (0.000)* |

Note: * shows the statistically significance at the 1% level. The numbers in the parenthesis show the p-values.

**Table 3**
Results of the CIPS panel unit root test.

| | Level | First Differences |
|---|---|---|
| LnCob | −2.178 | −3.778* |
| LnGDP | −1.837 | −4.119* |
| LnK | −2.663* | |
| LnL | −3.841* | |

Note: * shows the statistical significance at the 1% level. The critical value at the 1% level is −2.60.

**Table 4**
Panel cointegration test results.

| | Test Statistics | p-value |
|---|---|---|
| Group | 2.626** | 0.013 |
| Panel | 5.435* | 0.000 |

Note: * and ** show the statistical significance at the 1% and 5% levels, respectively.

in Congo; that is, there is a natural curse for cobalt in Congo. The existence of a resource curse in Congo is expected since nowhere in the world resource abundance management has been so much poor and more visible than in DRC. DRC is considered to be a fragile post-conflict country at both the national and local levels; it is regarded as the textbook forum for resource-induced conflict. The majority of the Congo basin region lies in Congo, which has abundant of mineral resources. But this country is heavily dependent on agriculture and forestry, and it also has massive deficiencies in its infrastructure. The country has not been successful in utilizing the resources mainly because of the conflicts, which are either violent or non-violent, connected with natural resources (Matti, 2010).

We do not find any evidence of a resource curse for Canada. Specifically, we find that a 1% increase in cobalt production is associated with a 0.033% increase in per capita real GDP. This is in contrast to Bildirici and Gokmenoglu (2019), who found evidence of a resource curse for Canada in terms of gold and copper production; however, their result for silver did not support the result of the resource curse. Moreover, capital and labor have positive and significant impacts on GDP, while the effect of labor on GDP is more pronounced and higher compared to other variables. A 1% increase in labor and capital increases GDP per capita by 0.627% and 0.078%, respectively. The Canadian government (2021a) reports that in terms of cobalt, Canada is a key producer worldwide, and its mineral sector has a significant effect on supporting jobs as well as economic activity in each region. The mining and industry related to this contributes approximately $97 billion annually to the GDP of Canada and also employs over 625,000 people (Government of Canada, 2021b).

In the case of Cuba, a 1% increase in Cobalt production increases real GDP per capita by 0.035%, which supports the claim that cobalt is considered a blessing for Cuba. Thus, we fail to find any evidence of a resource curse for Cuba. For capital and labor, we also find evidence of a significant positive impact on real GDP per capita.

In the case of Morocco and South Africa, we do not find any evidence or effect of cobalt on real GDP per capita. This indicates that cobalt production in these two countries is not significant enough to influence the economic performance of these countries. However, in terms of capital and labor, while these variables do not have a significant impact on Morocco's GDP per capita, they do significantly affect the performance of the South African economy. In particular, we find that capital has a positive impact and labor has a negative impact on real GDP per capita. One other key difference is that while Morocco's cobalt production has a positive impact, South Africa's cobalt production has a negative impact. This indicates that there is a possibility of a resource curse in South Africa. This confirms the hypothesis of Elbra (2013) who stated that the country's experience with the extraction of minerals resembles the literature on resource curse, representing its neighboring countries in Sub-Saharan Africa.

**Table 5**
Long-run coefficients.

| Australia | | |
|---|---|---|
| Variable | Coefficient | p-value |
| LnK | 0.003 | 0.930 |
| LnCob | 0.007 | 0.482 |
| lnL | 0.097 | 0.735 |
| Constant | 10.726* | 0.000 |
| *Canada* | | |
| Variable | Coefficient | p-value |
| LnK | 0.078*** | 0.053 |
| LnCob | 0.033* | 0.000 |
| lnL | 0.627* | 0.003 |
| Constant | 10.194* | 0.000 |
| *Congo* | | |
| Variable | Coefficient | p-value |
| LnK | 0.030 | 0.664 |
| LnCob | −0.093* | 0.002 |
| lnL | −1.048 | 0.192 |
| Constant | 4.750* | 0.000 |
| *Cuba* | | |
| Variable | Coefficient | p-value |
| LnK | 0.118* | 0.000 |
| LnCob | 0.035* | 0.000 |
| lnL | 1.360* | 0.000 |
| Constant | 8.617* | 0.000 |
| *Morocco* | | |
| Variable | Coefficient | p-value |
| LnK | −0.042 | 0.694 |
| LnCob | 0.034 | 0.177 |
| lnL | −0.014 | 0.958 |
| Constant | 7.836* | 0.000 |
| *Russia* | | |
| Variable | Coefficient | p-value |
| LnK | 0.504* | 0.000 |
| LnCob | 0.062* | 0.005 |
| lnL | 0.125 | 0.718 |
| Constant | 5.334* | 0.000 |
| *South Africa* | | |
| Variable | Coefficient | p-value |
| LnK | 0.250* | 0.000 |
| LnCob | −0.004 | 0.558 |
| lnL | −0.274** | 0.020 |
| Constant | 6.736* | 0.000 |
| *Panel* | | |
| Variable | Coefficient | p-value |
| LnK | 0.134*** | 0.059 |
| LnCob | 0.011 | 0.582 |
| lnL | 0.125 | 0.658 |
| Constant | 7.742* | 0.000 |

Note: *, **, and *** show the significance at the 1, 5, and 10% levels, respectively.

For Russia, we find that cobalt has a positive and significant impact on real GDP per capita. In particular, a 1% increase in cobalt production increases real GDP per capita by 0.062% in this country. This contradicts the statement by Treisman, who said that this country is often considered to be the classic case of a resource curse, primarily because of oil and gas (Treisman, 2010). But our result matches that of Alexeev and Chernyavskiy (2014), who found a positive impact of resources on economic growth for Russian regions. On the other hand, from the result, we find that the coefficient of capital is also significant while labor is not.

Next, we test the causality relationship among the variables via the panel EK test and report the results in Table 6.

The results in Table 6 indicate that there is a unidirectional causality runs from LnGDP to LnK in Canada, Congo, Cuba, and South Africa, and bidirectional causality between LnGDP and LnK in Russia. There exists a

**Table 6**
Causality test results.

| | LnGDP $\nrightarrow$ LnK | | LnK $\nrightarrow$ LnGDP | | LnGDP $\nrightarrow$ LnCob | | LnCob $\nrightarrow$ LnGDP | |
|---|---|---|---|---|---|---|---|---|
| Countries | Test Statistics | p-Value | Test Statistics | p-Value | Test Statistics | p-Value | Test Statistics | p-Value |
| Australia | 2.049 | 0.359 | 0.485 | 0.784 | 15.294* | 0.000 | 0.404 | 0.817 |
| Canada | 4.619*** | 0.099 | 0.876 | 0.645 | 16.489* | 0.000 | 1.400 | 0.497 |
| Congo | 9.890* | 0.007 | 0.677 | 0.713 | 0.185 | 0.912 | 0.260 | 0.878 |
| Cuba | 10.680* | 0.005 | 2.724 | 0.256 | 5.302*** | 0.071 | 2.314 | 0.314 |
| Morocco | 2.238 | 0.327 | 10.755* | 0.005 | 0.641 | 0.726 | 4.217 | 0.121 |
| Russian Federation | 8.374** | 0.015 | 17.433* | 0.000 | 2.117 | 0.347 | 14.519* | 0.001 |
| South Africa | 8.288** | 0.016 | 2.380 | 0.304 | 1.332 | 0.514 | 3.169 | 0.205 |
| Panel Fisher | 46.137 | | 35.331 | | 41.360 | | 26.283 | |
| Bootstrap cv (10%) | 72.693 | | 73.976 | | 74.075 | | 72.803 | |
| Bootstrap cv (5%) | 108.114 | | 106.986 | | 111.332 | | 104.882 | |
| Bootstrap cv (1%) | 282.278 | | 302.906 | | 318.379 | | 271.327 | |
| | LnGDP $\nrightarrow$ LnL | | LnL $\nrightarrow$ LnGDP | | LnCob $\nrightarrow$ LnK | | LnK $\nrightarrow$ LnCob | |
| Countries | Test Statistics | p-Value | Test Statistics | p-Value | Test Statistics | p-Value | Test Statistics | p-Value |
| Australia | 0.884 | 0.643 | 0.359 | 0.836 | 8.467** | 0.015 | 7.585** | 0.023 |
| Canada | 1.604 | 0.449 | 1.657 | 0.437 | 3.646 | 0.162 | 5.098*** | 0.078 |
| Congo | 176.508* | 0.000 | 0.062 | 0.969 | 76.944* | 0.000 | 1.054 | 0.590 |
| Cuba | 2.461 | 0.292 | 1.680 | 0.432 | 3.541 | 0.170 | 6.978** | 0.031 |
| Morocco | 9.651* | 0.008 | 2.720 | 0.257 | 3.675 | 0.159 | 1.489 | 0.475 |
| Russian Federation | 0.190 | 0.909 | 1.317 | 0.518 | 4.631*** | 0.099 | 0.478 | 0.787 |
| South Africa | 17.976* | 0.000 | 1.046 | 0.593 | 1.425 | 0.490 | 3.772 | 0.152 |
| Panel Fisher | 209.275** | | 8.840 | | 102.330*** | | 26.456 | |
| Bootstrap cv (10%) | 75.391 | | 73.780 | | 74.412 | | 73.079 | |
| Bootstrap cv (5%) | 117.066 | | 111.376 | | 108.238 | | 110.444 | |
| Bootstrap cv (1%) | 284.610 | | 280.729 | | 279.801 | | 293.911 | |
| | LnCob $\nrightarrow$ LnL | | LnL $\nrightarrow$ LnCob | | LnK $\nrightarrow$ LnL | | LnL $\nrightarrow$ LnK | |
| Countries | Test Statistics | p-Value | Test Statistics | p-Value | Test Statistics | p-Value | Test Statistics | p-Value |
| Australia | 0.040 | 0.980 | 14.322* | 0.001 | 1.380 | 0.502 | 3.482 | 0.175 |
| Canada | 4.119 | 0.128 | 6.914** | 0.032 | 1.101 | 0.577 | 0.179 | 0.915 |
| Congo | 257.919* | 0.000 | 3.381 | 0.184 | 242.141* | 0.000 | 32.609* | 0.000 |
| Cuba | 2.794 | 0.247 | 0.938 | 0.626 | 1.041 | 0.594 | 8.004** | 0.018 |
| Morocco | 11.375* | 0.003 | 0.992 | 0.609 | 39.276* | 0.000 | 1.409 | 0.494 |
| Russian Federation | 1.024 | 0.599 | 1.687 | 0.430 | 0.694 | 0.707 | 0.431 | 0.806 |
| South Africa | 9.238** | 0.010 | 5.799*** | 0.055 | 2.075 | 0.354 | 0.656 | 0.720 |
| Panel Fisher | 286.508** | | 34.033 | | 287.708** | | 46.769 | |
| Bootstrap cv (10%) | 80.067 | | 75.646 | | 70.057 | | 73.467 | |
| Bootstrap cv (5%) | 114.276 | | 115.772 | | 107.322 | | 105.405 | |
| Bootstrap cv (1%) | 342.175 | | 305.387 | | 261.033 | | 253.759 | |

Note: *, **, and *** show the significance at the 1, 5, 10% levels, respectively. Bootstrap Critical values are obtaine using 10,000 simulations.

unidirectional from LnGDP to LnK for South Africa and from LnK to LnGDP in Morocco. We found a unidirectional causality from LnGDP to LnCob in Australia, Canada, and Cuba and from LnCob to LnGDP in Russia. There exists a unidirectional causality from LnGDP to LnL in Congo, Morocco, and South Africa. A bidirectional causality exists between LnCob and LnK in Australia. A unidirectional causality runs from LnCob to LnK in Congo and Russia and from LnK to LnCob in Canada and Cuba. There is also a unidirectional causality from LnCob to LnL in Congo and Morocco, from LnL to LnCob in Australia and Canada, and a bidirectional causality runs between these two variables in South Africa. We also search for the causality between LnK and LnL; the results indicate that there is a unidirectional causality exists from LnK to LnL in Morocco and from LnL to LnK in Cuba. There exists bidirectional causality between them only for Congo. When we focus on the results of panel causality test results, we reveal that there is a bidirectional causality runs from LnGDP to LnL, from LnCob to LnK, from LnCob to LnL, and from LnK to LnL.

## 6. Conclusion and policy recommendations

Cobalt is mainly extracted as a byproduct of copper and nickel. It is a potentially critical metal since it is used not only for manufacturing high-performance alloys but also for lithium-ion battery making. Global demand for cobalt continues to grow because of the energy and battery requirements of a transition towards a low carbon economy. Cobalt is extracted as a byproduct of other metals; hence its supply is dependent on host metals' mining. Approximately half of the world's cobalt supply is found in the DRC and extracted by both multinational mining companies and unregulated artisanal mines. From this aspect, cobalt supply is very sensitive to constraints in the future due to political instability, discouraging mining policies, or trade restrictions. This means the development of reliable and responsible sourcing of the mineral requires not only efficient mining but also promoting sustainable development and human rights protections. In this research, we sought to analyze the research curse hypothesis in terms of cobalt for several countries using second-generation panel data techniques.

From the resource curse perspective, the long-run relationship between the LnCOB and LnGDP exhibits three different results; while the findings point out a resource blessing for Canada, Cuba, and Russia, there is a natural resource curse for cobalt in DRC. In the case of Australia, Morocco, and South Africa, we do not find any evidence or effect of cobalt on real GDP per capita.

Natural resources' role in stimulating economic growth is vital for the economic well-being of a country. However, the abundance of natural resources in a country deteriorates the terms of trade and causes these countries to exhibit a lower economic growth performance compared to countries with no or relatively fewer natural resources due to the transfer of natural resource revenues to the same sector, excluding other sectors of the economy. For the DRC case, the economy's high dependence on resource extraction/export revenues, poor resource management practices, fragile political environment, socioeconomic and political problems such as widespread poverty, lack of physical and human capital, and the evidence for "rentier state" are probably the most important reasons supporting the validity of the resource curse hypothesis for the DRC economy. In other words, wealthy resources' legacy increases the fragility, and hence it undermines the economic growth. On the other hand, due to its vast cobalt resource endowment, DRC is economically defined as "the Saudi Arabia of the electric vehicle age" by experts. Therefore, the findings of our study and the above-mentioned definition for DRC are remarkably controversial. This curse can be avoided using different mechanisms. In our result, we found insignificant impacts of labor and capital on economic growth for DRC. However, labor and capital seem to have opposite effects, with labor having a negative coefficient and capital having a positive coefficient. In an economy, these two are the important resources that drive the economy forward. Therefore, the government needs to invest in a large amount of human capital in order to make the negative effect of labor into positive. According to Manning (2004), resources create distortions in the performance of an economy, and they are considered mechanisms of transformation. The authors said that in countries that are rich in resources if there is a low amount of human capital, it creates a curse for the economy. So it is not the existence of resources that creates a hindrance for the economy, rather, it can be related to the low level of human capital in that economy. Moreover, since capital exerts positive influence (although insignificant) on the growth, it is crucial for the government to provide large investment for the manufacturing sector, which might bring significant benefits to the economy afterward. For other economies, such as Canada, Russia, and Cuba, we found significant evidence of resource blessing. For Australia, Morocco, and South Africa, no evidence of the resource curse or blessing was confirmed. For Canada, Cuba, Russia, South Africa and the whole panel, the role of capital seems to be exerting significant influence on the growth of the economy as measured by real GDP per capita. This indicates that capital is a significant mechanism through which the resource curse can be possibly avoided. Therefore, these countries should finance the accumulation of physical capital via different incentives for the private as well as the public sector. In terms of labor, Australia, Canada and Cuba seem to have a positive effect on the economy. So significant benefits can be derived out of investment in labor in these economies. The whole panel result also seems to indicate this conclusion although the effect is not significant. However, for the countries whose coefficients for the labor is not significant or negative, we can infer that to bring the positive benefit out of labor, other mechanisms need to be sought. As capital seems to exert a positive influence on the economy, our analysis points out that capital investment can be a key to increasing human capital development as well as avoiding the resource curse.

In this study, we have only considered examining the resource curse hypothesis for cobalt. However, future research can examine the validity of the hypothesis for other key materials such as lithium and graphite. Moreover, we did not incorporate any institutional variable in this study that may influence the hypothesis of resource curse or blessing in the countries of study, therefore, future studies can incorporate this variable into account in order to provide a more comprehensive assessment in terms of policy recommendations.

## Credit author statement

**Veli YILANCI:** Conceptualization, Methodology, Writing- Reviewing and Editing. **Nermin Ceren TURKMEN**: Investigation, Visualization, Writing- Original draft preparation. **Muhammad Ibrahim SHAH**: Investigation, Writing- Reviewing and Editing.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data availability

Data will be made available on request.

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# Update

**Resources Policy**
**Volume 82, Issue , May 2023, Page**

**DOI:** https://doi.org/10.1016/j.resourpol.2023.103475

Resources Policy 82 (2023) 103475

Contents lists available at ScienceDirect

Resources Policy

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

# Corrigendum to "An empirical investigation of resource curse hypothesis for cobalt" [Resour. Pol. (2022) 102843]

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"Department of Resource Economics and Environmental Sociology (REES), University of Alberta, Edmonton, Canada" in this publication. However, since this work was not part of Muhammad Ibrahim Shah's thesis and not part of the work he does at the University of Alberta and no professors or supervisors from University of Alberta was involved in this paper, rather it was the result of his own personal interests, the author would like to remove the affiliation of the University of Alberta from this publication and replace it with the following affiliation: "Independent researcher, Edmonton, Canada". He would like to replace his University email mshah3@ualberta.ca with personal email: ibrahimecondu@gmail.com.

The authors would like to apologise for any inconvenience caused.

DOI of original article: https://doi.org/10.1016/j.resourpol.2022.102843.

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https://doi.org/10.1016/j.resourpol.2023.103475

Available online 24 March 2023
0301-4207/