“Will electric vehicles improve the developing world?” – An analysis of cobalt price impacts on the Democratic Republic of Congo’s economy.

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Abstract

As the demand of electric vehicles and lithium-ion batteries are projected to dramatically rise over the next ten years, countries with mineral deposits needed for the production of these technologies will become increasingly important in the global economy. This research has sought to evaluate the impacts of one of the most geographically concentrated and politically contentious minerals, cobalt, by using its price history on the London Metal Exchange, on the Democratic Republic of Congo's macroeconomic indicators such as exchange rates, total reserve holdings, and central bank rates. The Democratic Republic of Congo was chosen for this analysis as it is the world's largest cobalt producer and the largest holder of proven cobalt reserves. To complete the analysis, this research relied upon a vector autoregressive model, which was compiled with six lags, first-differenced variables, and subsequently followed by an impulse response function. The impulse response function modeled the response of differenced macroeconomic variables to a one standard deviation shock of logarithmic cobalt prices, yielding results that were both statistically insignificant and not causally related, in accordance with the Granger causality test. The results and the explanation for the findings were supported through a discussion of the local cobalt industry, the macroeconomic picture of the Democratic Republic of Congo, and the viability of vector autoregressive analysis.

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1 Historical Background and Introduction

Academics and economists have long studied the correlation between commodity prices and macroeconomic activity, as the world's nations have relied upon their natural resource endowments to generate revenues and promote economic growth. According to the United Nations Conference on Trade and Development, a country is considered to be "commodity-dependent" when more than 60% of its total merchandise exports are composed of commodities. One nation that fits this category is the Democratic Republic of Congo (DRC), where in 2019, commodities represented more than 95.2% of the nation's merchandise exports with 85.4% of exports being directly attributed to the mining industry. The DRC has historically been reliant on its commodities to generate economic activity; however, the control of resources and the subsequent distribution of wealth has an entangled history mingled with both colonial and post-colonial abuses and corruption.

In the late 19th and early 20th centuries, the DRC was a Belgian colonial state, first referred to as the Congo Free State and later as Belgian Congo. Under Belgian rule, the Congolese had exported agricultural and mineral commodity goods including rubber, cotton, palm oil, copper, and cobalt, with the agricultural commodity goods representing 27% and the mineral commodity goods representing 23% of the Gross National Product (GNP) respectively in 1955 according to the World Bank's International Bank for Reconstruction and Development. Despite the wealth of the Congo's commodity stock, revenues were siphoned away from the country by conglomerates such as the *Union Minière du Haut-Katanga,* an Anglo-Belgian mining company which was a subsidiary of the *Compagnie du Congo pour le Commerce et L'Industrie* (CCCI) and controlled by the Belgian Bank, *Société Générale de Belgique.* In the context of the scale of Belgian exploitation, historical estimates place 70% of the Congolese economy directly underneath *Société Générale's* control at the peak of Belgian rule (Munshi

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2020). Belgium's colonial history in the Congo, presents challenges for historical estimates of the relationship between international commodity prices and macroeconomic indicators, which lie at the heart of the goals of this document. Further difficulties for historical economic modeling stem from the period of 1971-1997 when today's DRC was historically known as Zaire. Zaire, a second-generation state of Congolese independence was formed under a coop led by Mobuto Sese Seko. Mobuto had ruled Zaire for the state's 32-year history and had maintained an economic and social rule known as "Mobutoism" which was characterized by the systematic oppression of independent economic and social activities. The kleptocratic nature of Mobuto's regime has been well documented and estimates place the amount of capital flight and imputed interest-earning losses from the nation at approximately $18 Billion by 1990, a staggering figured when compared with the country's registered external debt profile which was registered at $12.3 Billion in 1994 (Ndikumana and Boyce 1998).

Despite the historical data challenges, the purpose of this paper is to measure the importance of cobalt to the Congolese economy, and to demonstrate the results of forecasting macroeconomic variables using global cobalt prices and global commodity prices. The reason for pursuing this task using cobalt prices is two-fold, the first reason is that the government of the Democratic Republic of Congo has recently undergone its first peaceful transition of power with the election of Felix Tshisekedi, and the nation has signaled its interests in nationalizing sections of the cobalt industry through the creation of the *Entreprise Générale du Cobalt* (EGC). The EGC is a state-owned company that will carry monopoly rights for the purchase and sale of the country's hand-mined cobalt, vowing to use cobalt revenues in the same manner as Saudi Arabian Oil Company (ARAMCO) has historically used oil to boost the national coffers of the Saudi Arabian economy. The second reason for pursuing this topic is that cobalt represents one of the most important metals associated with the world's transition from traditional combustion engine technologies and towards the large-scale adoption of

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electric vehicles (EVs). Today, cobalt is largely used as a part of the cathodes or energy storage capacities of the lithium-ion batteries which power modern-classes of EVs and while the exact concentration of cobalt used in a lithium-ion battery can vary due to the size and make of the battery and the corresponding vehicle, the United States' Department of Energy's Argonne National Laboratory estimates that an average single car lithium-ion battery contains 14 kilograms of cobalt, as well as 8 kilograms of lithium, 35 kilograms of nickel, and 20 kilograms of manganese (Castelvecchi 2021). Cobalt is particularly unique among the minerals used in lithium-ion batteries because of the unique industry challenges that it presents, whether its environmental-social governance (ESG) concerns for developers of lithium-ion batteries who are focusing on capitalizing on sustainable business marketing, or the cost and supply chain concerns derived from most of the global cobalt supply being concentrated in the Democratic Republic of Congo.

Today the Democratic Republic of Congo represents the world's largest producer of cobalt, effectively outpacing the next largest producing nations of Russia, Australia, and the Philippines, as the DRC had produced approximately 70.5% of the world's cobalt in 2021, and 69.01% in 2020, according to the US Geological Society (Basov 2022). Compared with the other minerals needed for lithium-ion batteries, cobalt represents the most geological concentrated mineral, and opportunities for new mines are costly and unattractive for competing countries due to environmental and pre-operating expenses. Not only are opportunities for new mines costly, but they are scarce due to the deposits of cobalt worldwide. For reference, the DRC has the world's largest cobalt deposits with approximately 3.5 million tons, compared with Australia at approximately one million tons, followed by subsequent countries such as Cuba, Russia, the Philippines, and the United States which only contain marginal deposits in comparison. With the DRC's large concentration of cobalt, analysts suggest that the nation is set for large windfall revenues, especially as the demand for EVs is

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set to rise by approximately 36% annually according to the International Energy Agency, and as the global stock of EVs is expected to rise from 7 million in 2019, to 245 million in 2030, the demand profile of cobalt balloons to over 3.3 billion kilograms of cobalt (calculated at 14 kilograms per EV).

As the demand profile for cobalt has been increasing in recent years, and as the DRC has represented a historically significant provider of cobalt for global markets, this research was interested in modeling and measuring the impacts of cobalt price activity on DRC macroeconomic variables including exchange rates, liquidity reserves, local currency rates to the USD rates, and central bank rates. To measure the relationship of cobalt prices on the macroeconomy, my research relied upon a vector autoregressive model (VAR), and an impulse response analysis as both are highly popularized methods in the current academic dictum, not only for this country and commodity product group but also across other pairings of geographies and commodities. The results of the paper had found that the relationship between global cobalt prices and DRC's macroeconomic indicators widely failed the Granger causality test and that both global cobalt prices on the London Metal Exchange as well as the London Metal Exchange's commodity price index were unreliable metrics for forecasting DRC economic data. The findings of this model led to independent hypotheses that rely upon a profile of concerns regarding the Congolese cobalt industry as support for the claims.

This paper is organized as follows, section II provides an outline of the existing academic literature on vector autoregressive models and impulse response functions which model the relationship between commodity products and macroeconomic variables, section III describes the data sources used in the analysis, the choice of variables, and the methodology used, section IV begins with a visual interpretation of the relationship between cobalt prices and DRC macroeconomic variables, as well as the relationship between the London Metal Exchange's metal price index and the DRC's macroeconomic variables and follows with the employed

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methodology, alongside a brief commentary on the respective findings, section V highlights potential hypotheses for why the methodology is not-applicable for this research task despite a history of application in the existing academic literature, section VI provides the policy recommendations for the development of a responsible cobalt industry in the DRC as well as how the nation can develop non-commodity economic activity, and finally section VII provides the conclusion of the research, the role of this paper in the current academic literature and examples of subsequent research topics in this field of global economic policy writing.

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2 Literature Review

Currently in the academic literature, one of the most popularized methodologies for modeling the impacts of commodity price fluctuations on macroeconomic indicator variables is the vector autoregressive model. Originating in 1980, by macro econometrician Christopher Sims, academics widely consider VAR models to be an effective strategy for modeling causal relationships between macroeconomic variables as they change over time, furthermore VAR models are widely used throughout economic and financial forecasting scenarios. While the results of VAR models can vary due to factors such as the selection of the time horizon, the number of lagged terms, and the variable selection, comparing previous results of VAR models with the results of this paper are important for understanding the relationship between global cobalt prices and the Democratic Republic of Congo's economic indicators.

One of the most extensive and widely cited uses of a VAR model has been the work completed by Deaton and Miller (1995). In the paper the authors had examined the relationship between commodity prices and GDP components for thirty-two Sub-Saharan African countries from 1958-1992. The authors had used world prices of twenty-one commodity products (including metal products such as nickel, manganese, iron, and bauxite), the authors also weighed the prices by calculating the total value of the exports of the products in 1975 and then dividing the value of each commodities export in 1975 by the total value. In weighing the commodity prices the authors had recognized that they had lost the ability to track significant windfall effects such as new discoveries of oil. While the authors had found some evidence of a relationship between commodity price movements and GDP components, for many countries there were not statistically significant observations, and the authors note that while the correlation between commodity prices and economic growth may be real, it is not strong enough to allow inferences about the parameters.

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Building on the research of Deaton and Miller, a more contemporary paper from Chuke, Simpasa, and Oduor (2018) had used a structural VAR approach to study the impacts of commodity prices measured as the nominal price of crude oil on economic variables such as GDP growth, CPI inflation, exchange rate, external reserves, and government expenditure in seven African countries including Morocco, Zambia, and South Africa, which like the Democratic Republic of Congo, have a large percentage of their exports originating from mineral commodities. The authors findings were unique per country, with Morocco showing an inverse relationship of GDP to a commodity price shock, South Africa showing GDP growth responding to a two-period lag of a commodity price shock, and Zambia showing GDP growth five quarters after a commodity price shock. The authors results are particularly interesting for this analysis because their findings are not uniform across sub-Saharan African states, which suggests that the analysis conducted in this paper would contribute to their research as the Democratic Republic of Congo was an omitted African country.

Regarding the existing literature on VAR modeling commodity price impacts to the DRC's macroeconomic indicator variables, a recent research paper (Pinshi, 2018) studied the impacts of falling commodity prices, (using the index prices of precious metals), on macroeconomic variables including current account balances, total reserves, nominal exchange rates, real GDP, inflation (end of period), bank credits to the private sector, and bank deposits. The author's time frame specifically focuses on the sharp decline in commodity prices experienced in 2015, and the author provided a demonstration of the percentage change in macroeconomic variables from 2014 to 2016 to note the correlation between the two. The paper's conclusions relied upon the results of a 24-month commodity price shock found through impulse response functions, which found that macroeconomic variables responded negatively across all categories including the real sector, the public sector, the external sector, and the financial and monetary sectors. The analysis of the former Congolese analysis forms part of the basis for this paper's

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analysis, with this paper providing an additional five years of time series data. The results found in the twelve-year analysis provided less conclusive findings than the analysis of time series data with six-years analysis.

Research using VAR models, extends beyond the African continent, and for my analysis, I had considered the literature conducted on another mineral-rich economy, Chile. The analysis done for Chile, focused on the impacts of copper price shocks on Chilean interest rates, headline CPI, the foreign exchange rate, and chained GDP. Using a structural VAR model, the paper had demonstrated that a 10% price shock due to supply factors results in both currency appreciation, and declining GDP activity, however the findings for the other variable were not statistically significant (Pederson, 2015). Historically the relationship between the Chilean economy and copper prices have been described by researchers and economists in diverse ways with larger data availability than Sub-Saharan Africa is well-documented. For the Chilean economy there are numerous research pieces to consider, but one paper specifically stood out for its description of the relationship through an IMF-documented cyclical evaluation (Spilimbergo, 1999). The paper's methodology relied upon lagged regression analysis, measuring both the short-run and long-run correlation of consumption, investment, exchange rates, and GDP during periods such as copper price booms and copper price declines. The findings of the analysis were that changes in the nominal exchange rate are strictly correlated with the copper cycle, as the nominal exchange rate appreciates during price booms, and depreciates as the price declines, while investment and business cycle indicators had followed the copper cycles albeit to a small degree. As the Chilean analyses had provided significant insights into the relationship between a metal exporting economies' macroeconomic variables and the global price of the exported metal, my research paper has sought to maintain the spirit of both the analyses through similar descriptions of Congolese economic variables with cobalt.

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3 Methodology and Data

For this analysis, I referenced the existing academic literature as to which macroeconomic variables would be suitable for this modeling task. Typically, regarding macroeconomic variable data, there are different modeling options, but because of the lack of official data resources for the Democratic Republic of Congo, the choices were largely pre-selected due to factors such as the availability and reliability of economic data on the country. As mentioned throughout the previous analysis done on Sub-Saharan African countries, the lack of reporting causes difficult challenges in establishing historical relationships, and due to data availability and because of my reference to a previous analysis done on the Democratic Republic of Congo, the selected time horizon ranges from January 2010 to March 2022, creating a total of 147 time-series observations. The time horizon is significant for this analysis because it is at this point where other commodity products such as diamonds and crude petroleum, no longer represent the top two highest export products of the Democratic Republic of Congo, with export shares of the products dropping to lower than 3% beginning in 2015 according to the Observatory of Economic Complexity. The selected variables were those with data available at the highest frequency, and therefore only variables with monthly observations were selected, this includes data on international liquidity i.e., total reserve holdings, domestic currency per US dollar rates, the real effective exchange rate based on local CPI, and the central bank rate. The data for cobalt prices was gathered using Trading Economics, which has sourced the daily prices for cobalt from the London Metal Exchange. For additional analysis and to confer my findings, I also performed a VAR analysis using the Commodity Metal index, which was sourced from the International Monetary Fund. The macroeconomic variables selected were sourced from the International Monetary Fund's International Financial Statistics (IFS) database.

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While the variables were chosen in part due to their availability, frequency, and references by previous academics, there is still valuable pieces of information that were sought to be understood by choosing these variables. For example, my initial intuition about the relationship between the amount of liquidity held by the Congolese government and commodity prices would be that as commodity prices such as cobalt rise, the exporting sectors of the economy would receive more liquidity and therefore would have more taxable income that the government may either consequently spend or save, depending on whether the government has a pro-cyclical or counter-cyclical fiscal policy. Using cobalt prices in my initial hypothesis would provide indicators for which fiscal policy the government has historically taken and what policy we would expect the government to take in the future. For the exchange rate of the domestic currency per USD, as well as the real effective exchange rate based on CPI, my initial expectations were that a positive shock to cobalt, such as seen with increased demand for EVs, would carry results that are consistent with the portfolio balance model, and that there would be a balance of payments surplus, and an increase in foreign holdings of the country's currency thus leading to an increase in the demand for the country's currency and positive currency returns (Chan, Tse, and Williams 2009), nevertheless the analysis' results show that such an explanation is not feasible to ascertain. The final indicator was the central bank rate, and while I had expected to find a lagged response to international cobalt price shocks, I had still expected to see higher rates follow cobalt price increases as the additional funds entering the Congolese economy from international markets would increase the money supply, and subsequently lead to an inflationary economic setting. To evaluate my various theories, my first step in the analysis was noting any trends in the time series sequences.

As my variables are interconnected in the macroeconomic setting, I had found that an effective modeling strategy for measuring the interconnectivity of the variables with cobalt prices, was to implement a VAR model. The VAR model captures the evolution of endogenous

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variables over time, using linear functions of the variables captured in a vector. Using the VAR is particularly used before conducting an impulse response analysis. The VAR analysis is able to generate an impulse response function, after deriving the moving average vector representation in accordance with Wold's decomposition theorem. The moving average vectors allows for the measurement of shocks to one of the variables (in the case of this analysis, cobalt price) to the response variables (Congolese macroeconomic indicators). With an understanding of the basic notions of a VAR model, my basic equation was as follows:

1. $X_{t,1} = a_1 + \emptyset x_{t-1,1} + \emptyset x_{t-1,2} + \emptyset x_{t-1,3} + \emptyset x_{t-1,4} + \emptyset x_{t-1,5} + w_{t,1}$
2. $X_{t,2} = a_2 + \emptyset x_{t-1,1} + \emptyset x_{t-1,2} + \emptyset x_{t-1,3} + \emptyset x_{t-1,4} + \emptyset x_{t-1,5} + w_{t,2}$
3. $X_{t,3} = a_3 + \emptyset x_{t-1,1} + \emptyset x_{t-1,2} + \emptyset x_{t-1,3} + \emptyset x_{t-1,4} + \emptyset x_{t-1,5} + w_{t,3}$
4. $X_{t,4} = a_4 + \emptyset x_{t-1,1} + \emptyset x_{t-1,2} + \emptyset x_{t-1,3} + \emptyset x_{t-1,4} + \emptyset x_{t-1,5} + w_{t,4}$
5. $X_{t,5} = a_5 + \emptyset x_{t-1,1} + \emptyset x_{t-1,2} + \emptyset x_{t-1,3} + \emptyset x_{t-1,4} + \emptyset x_{t-1,5} + w_{t,5}$

The above example of a VAR model is an example of a vector autoregressive model of order one, or VAR(1), and each equation is modeled with a constant term, and an error term, respectively. While the above model is an example of the VAR that was implemented in analysis, there were a number of steps that had to be completed beforehand, including visual inspections of the dataset, testing for stationarity, and finding the optimal lag length using fit measurements. The steps after preparing the VAR model, include generating the impulse response analysis, and checking for "causal" relationships between the forecasting variables.

The visual inspection of my variables was the primary step taken in the methodology, this is because insights regarding stationarity, the optimal lag length, and the forecasting power of the variable of interest can all be gathered through an initial scan, my insights along with the corresponding plots are available in Section IV of this analysis. Through the visual inspection, the primary motivation was to evaluate whether the time series dataset showed any signs of

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stationarity. Stationarity is defined as the statistical properties of a time series not changing over time while the overall behavior of the time series remains consistent throughout the period of interest. In the visual inspection, other forecasting concerns were evaluated such as seasonality effects or trends in the time series data. As the data of interest is being measured monthly, the likelihood of seasonal effects and trends increases, therefore, to deal with these concerns, I had routinely performed a unit root test. The unit root is a characteristic of a time series that can cause the series to be non-stationary, this is because the unit root causes a systematic pattern that is not predictable in forecasting scenarios. To assess for the presence of a unit root, I used the Augmented Dickey-Fuller test, which measured the null hypothesis of whether a unit-root was present in the time series. The Augmented Dickey-Fuller test, while powerful still presents opportunities for Type I errors (false positives) to occur, and therefore any analysis done to find stationarity time series values was complemented with a visual inspection to ensure that no trend or seasonal effects were present.

As with most monthly macroeconomic observations, the time series data had first registered as non-stationary in levels, and therefore I had conducted transformations to the time series, which included a logarithmic transformation to the cobalt pricing data, and a first-difference transformation across all the macroeconomic variable data. The descriptions of the data that were used for the analysis, as well as the subsequent transformations that occurred can be found in the appendix section of this analysis.

Once the data had become stationary, I had continued to prepare my VAR model through finding the optimal lag length, this included a series of fit measurements such as the Akaike Information Criteria (AIC) and the Bayesian Information Criteria (BIC), which were used to judge the optimal lag length which I had set to be selected between 1 and 24 lags (representing a range of 1 months to 2 years). The optimal lag length is a key factor in completing the VAR analysis because it allows for the measurement of the relationship of one variable to another at

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different points in time. For example, the impact of rising cobalt prices may not be felt on the liquidity reserves or the exchange rate in one month, but rather six months, perhaps due to either policy decisions or other economic phenomenon occurring. The choice of using both the AIC and the BIC judgements were to ensure that the estimators do not overfit or underfit the optimal lag length. As the optimal lag length was selected, the next step was to generate the VAR model, its outputs, and its forecast variables. Once the VAR model was generated, the coefficient terms were generated for which I then used to create the forecasts for each relationship, the corresponding graphs were also generated and are provided in the appendix section. Once the VAR model and the forecasts were generated, I proceeded with the impulse response analysis, allowing for a visual interpretation of the impacts of the macroeconomic variables to a one standard deviation shock to global cobalt prices. While the analysis and the forecast plots are both useful and insightful, it was not until I had followed with the Granger causality test, that I was able to understand the relationship between the variables and whether any of the preceding analyses, such as the VAR model and the impulse response model, were statistically significant. In general, the Granger causality test was particularly useful due to its computational ease, yet it is worth mentioning that the test was not a measure of "true causality" and only a measure of "predictive causality" as it only describes in-sample fitting and not out-of-sample forecasting.

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4 Modeling and Implementation

To effectively model the impacts of cobalt prices on Congolese macroeconomic variables, understanding the dataset and existing trends is a crucial part of the process, to do this I had relied upon a visual inspection (Figure 1). The first time series variable that I had evaluated was the global monthly average cobalt prices measured in USD per ton. In the time frame the results ranged from lows of approximately 20,000 USD per ton to highs of approximately 80,000 USD per ton. As cobalt prices widely varied during the series, there were some observable general trends, for example, cobalt prices first underwent a steadily declining period from 2010 to 2013, then prices began steadily increasing from 2013 to 2016, before experiencing a sharp increase from nearly 20,000 USD per ton to 80,000 USD per ton from 2016 to 2018, the sharp increase was paired with sharp decline which set prices back to levels seen throughout most of the early part of the decade, at 20,000 – 40,000 USD per ton. At the end of the cobalt price time series, an observable record price rally had occurred leaving prices hovering near 80,000 USD per ton. The rallies in cobalt pricing that had occurred from 2016 to 2018 and from 2020 to early 2022, are widely attributed to the momentum of the EV business according to market analysts from both Bloomberg and CRU, however, the responsiveness of local producers in the DRC along with the tendencies of market speculators on the EV industry have shown that high cobalt prices have been historically difficult to maintain long term.

Compared to the cobalt prices series, the macroeconomic variables share similarities in trends, as for most the data points a stable range of data will be interrupted by a quick spike that is either maintained or tails off. While there are similarities between cobalt prices and the indicator data, no clear corollary trends could be estimated based on the visual inspection alone. The first macroeconomic variable evaluated was the international liquidity and total reserve holdings of the DRC, this reserve holdings did not include gold and USD holdings, and the metric ranged from less than $1 Billion USD equivalent in holdings to over $3 billion USD

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equivalent in holdings. The reserve holdings have been historically steady ranging from $1 billion USD to $2 billion USD from 2010 to 2016, however the reserve profile declined during 2016 and only returned to levels seen at the beginning of the time horizon in 2020 with the reserve holdings dramatically increasing to over $3 billion USD. The second variable of interest was the exchange rate of Congolese Francs to USD (domestic currency per USD, measured as a period average, and this variable moved more steadily throughout the time horizon with large increases seen in 2016, rising from approximately 1000 Congolese Francs per USD to 1500 Congolese Francs per USD, and 2020, where the rate rose to nearly 2000 Congolese Francs per USD. The next time series variable was the real effective exchange rate, based on the local Consumer Price Index (CPI), which according to the IMF is a measurement of the value of the Congolese Franc against a weighted average of foreign currencies, divided by the CPI. The real effective exchange rate implies that if the rate increases, exports are more expensive and imports are cheaper, an increase would mean that the DRC would suffer a loss in international trade competitiveness. Based on the time series, the real effective exchange rate underwent periods of increases from 2011 to 2016, a sharp period of decline from 2016 to 2018, and another rising period from 2018 to 2020. These periods are seemingly aligned if considering a lag response to cobalt price activity, but like the other macroeconomic variables, further statistical modeling was required to evaluate the strength of any possible relationships. The last series of time series observations was the central bank rate, which upon inspection seemed to be the most unlikely variable to be impacted by cobalt prices. According to the time series, the central bank rate ranged below 40% across for nearly half of the period, and there were only slight increases which had occurred from 2016 to 2018 and from 2020 to 2021, as the central bank rate hovered closer to 20%.

The preliminary visual inspections were not able to provide any meaningful leads as to whether cobalt prices impact Congolese macroeconomic indicators, however, as a part of the

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vector autoregression analysis, ensuring that the variables are stationary was a preliminary aspect of completing the analysis. Upon initial evaluation, the time series data appeared to be non-stationary as there were varying results across the time horizon and a complementary unit root test (Augmented Dickey-Fuller) was done to ensure that the time series variables were indeed non-stationary. In the first unit root test, the time series variables were confirmed to be non-stationary excluding the time series for the central bank rate, nonetheless the visual inspection shows more variation than the unit root test may have captured, and therefore I proceeded with the decision to transform the dataset using both logarithmic and differencing techniques. The first transformation performed was to find the logarithm of cobalt pricing data, as understood by the academic literature, logarithmic transformations are useful in demonstrating the % change in price data and therefore measuring the magnitude of price changes relative to the macroeconomic variables of interest. As the logarithm of the cobalt price was taken, an additional stationary check was performed, and it was found that the logarithmic transformation did not result in a stationary reading of the Augmented Dickey-Fuller test, therefore I had proceeded to perform a first differencing transformation across all the variables. The visual results of the transformation are outlined in the chart seen in Figure 2.

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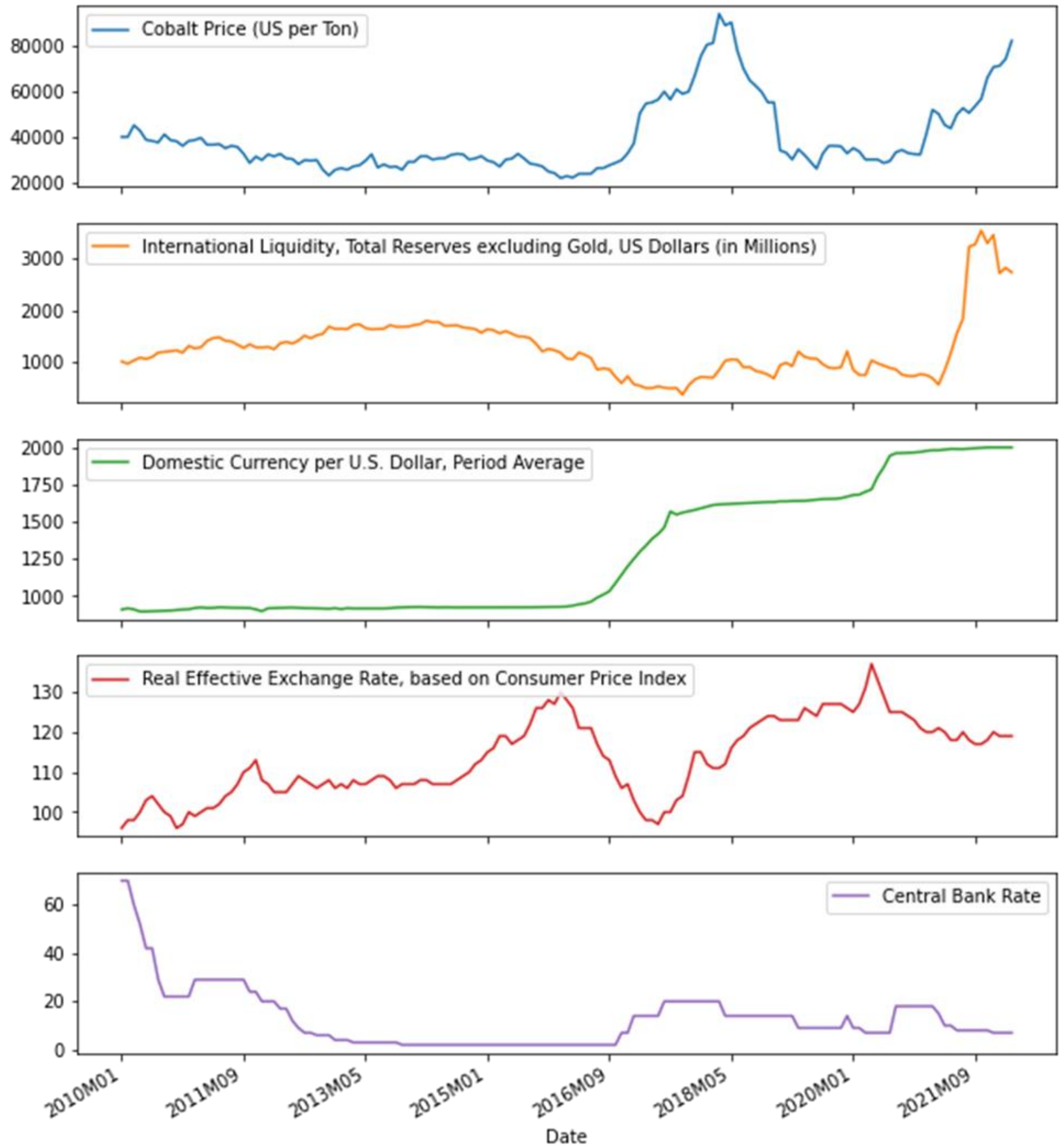

Figure 1: Time-series observations of global cobalt prices and DRC macroeconomic variables.

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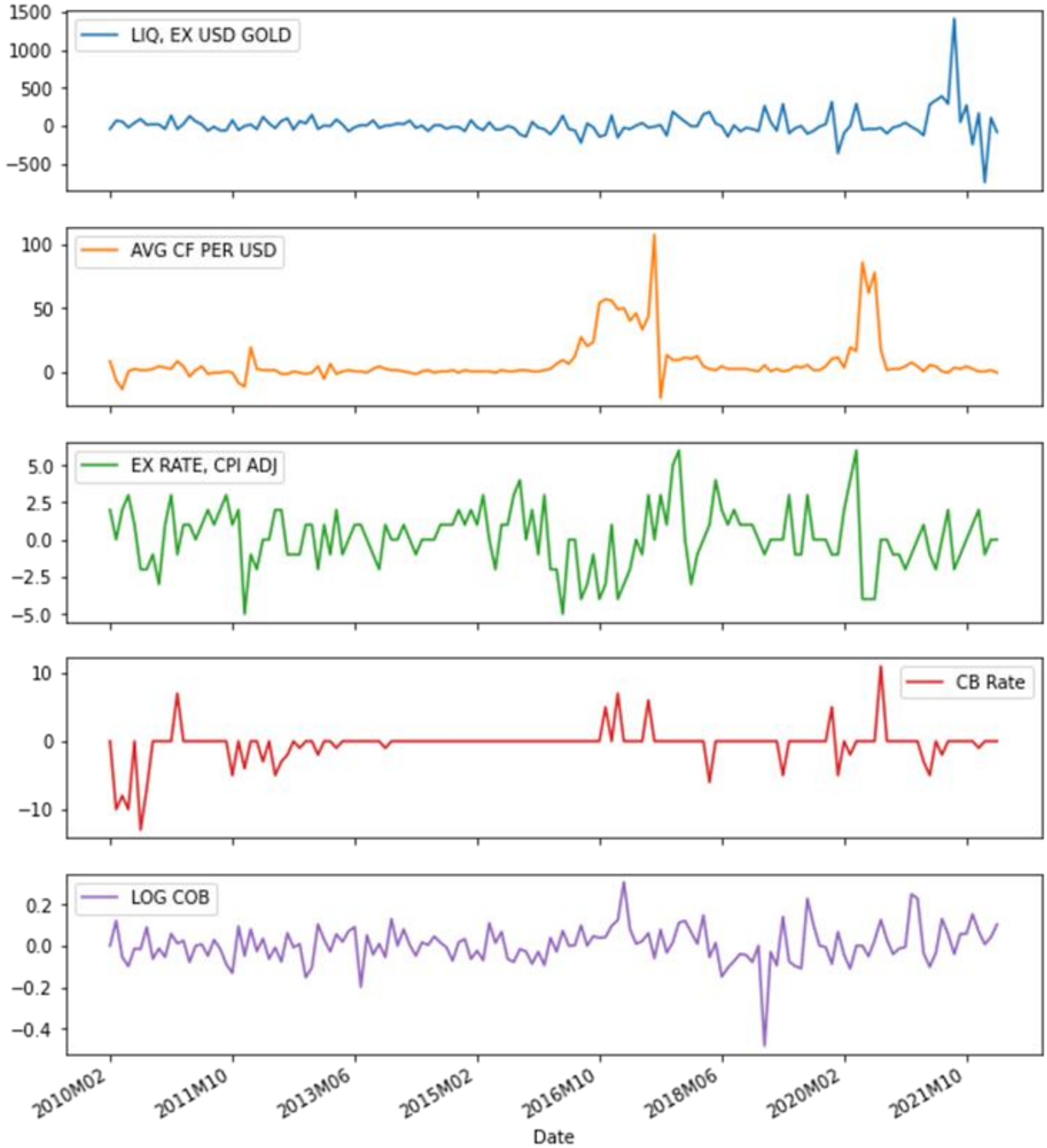

Figure 2: Time-series observations of logarithmic global cobalt prices and first-differenced DRC macroeconomic variables.

As can be seen in Figure 2, the transformations have made the time series resemble a stationary series, and while to a causal reader there may be concerns regarding the size of the large cycles, these were considered to be aperiodic and therefore the first-differenced time series was characterized as a stationary dataset. To be confident about the stationarity of the data, I again performed the Augmented Dickey-Fuller test and found that I was able to reject the null hypothesis that a unit root was present as the p-values of the test were below the threshold significance value of 0.05. As the time series was stationary in first differences, I proceeded to find the appropriate lag value for the model. Observing the trends, I speculated that the appropriate lag term would correspond to either semi-annual or annual time frames, and therefore I had evaluated the optimal lag length within twenty-four lags, using the AIC and BIC series of fit measurements. The optimal lag length was determined at the point where the figures were at relative minimums meaning the last lag point before the AIC and BIC series began increasing again. Evaluating the AIC and BIC results led to numerous candidates for the optimal lag length, including a lag length of one as the reading had a relatively low BIC of 14.546, and a lag length of 6 with a low AIC reading of 13.933 (the full table is available in the appendix section of this analysis). The decision was to use a lag length of 6 to create a VAR(6) model, primarily because a VAR(1) model tended to demonstrate a weaker relationship between cobalt prices and the macroeconomic variables of interest, and in reality it would be unlikely to see many of the macroeconomic variables such as the central bank rate or the exchange rate leveraged on CPI be affected in such a short time frame by a historically volatile price metric. The VAR(6) model computes five equations with each equation containing the five variables and their six lagged terms, combining for a total of thirty terms in the equation. While the VAR forecasts are insightful for the analysis, the true purpose of using the VAR model is use the model’s moving average vector for an impulse response analysis. The benefit of the impulse response analysis is that it allows for measuring the impacts of

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cobalt price activity on the macroeconomic variables, more specifically, it measures the response of a one standard deviation shock of log cobalt prices to each of our macroeconomic variables. The results of the impulse response are seen in Figure 3.

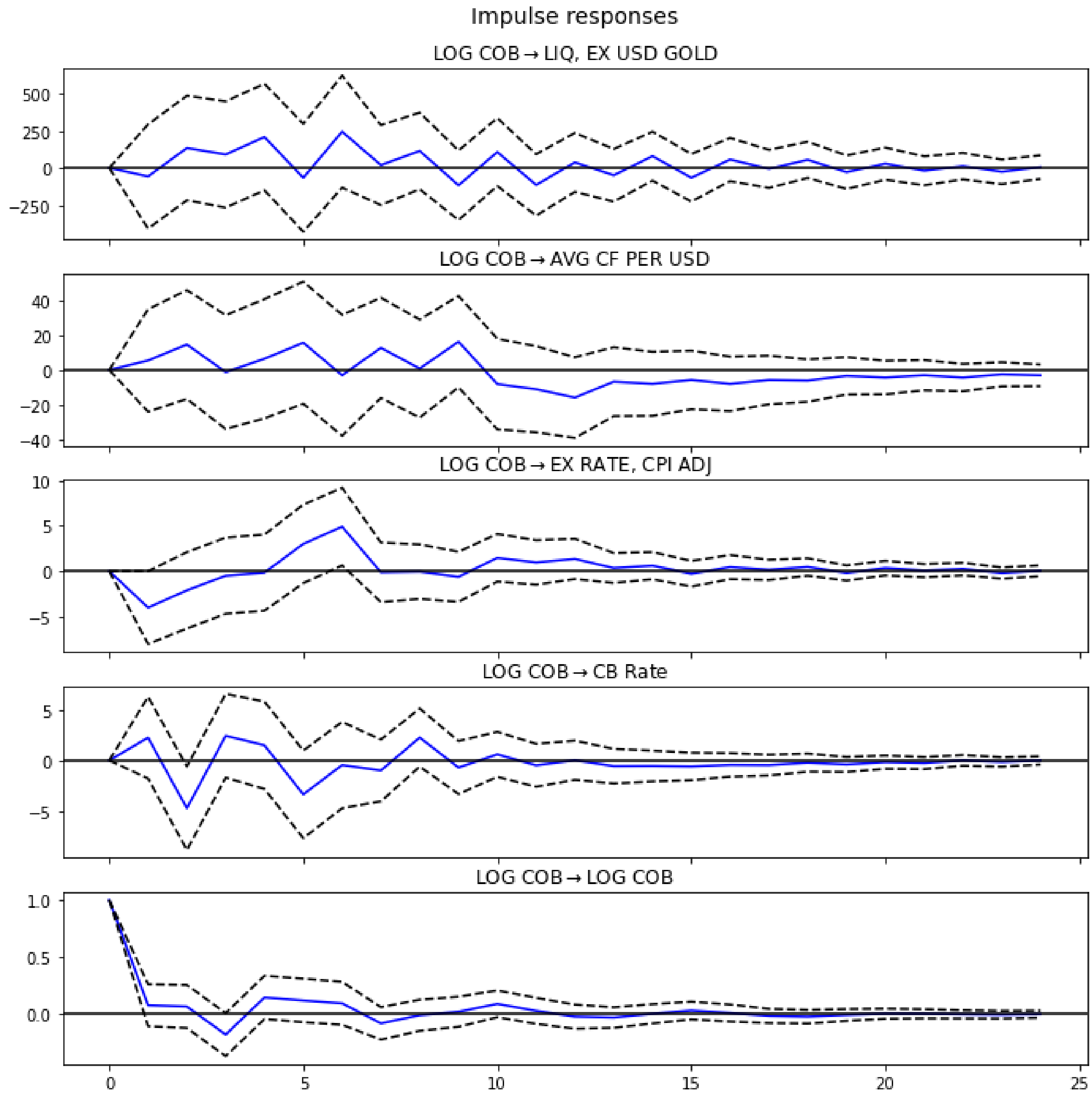

Figure 3: Impulse response graphs of logarithmic global cobalt prices on DRC macroeconomic variables.

The results of the impulse response functions demonstrate meaningful insights regarding the relationship between changing global cobalt prices and the Democratic Republic of Congo's macroeconomic indicators. The impulse response functions represent a reaction of the macroeconomic variables to a one standard deviation shock of log cobalt prices. While the magnitude is not set at the projected levels of increased EV demand, the relationships are important for understanding whether cobalt prices carry causal and statistically significant relationships to liquidity, exchange rates, or central bank rates. In the impulse responses of both cobalt prices on reserve rates and the average exchange rate of Congolese Francs per USD, there are not statistically significant relationships because the standard deviation of the results are both less than and greater than zero. The impacts of cobalt prices on the CPI-adjusted exchange rates are meaningful for interpretation as it can be seen that a one standard deviation shock of log cobalt prices, results in a decrease in exchange rates in the first period, and in 5-6 periods the exchange rates increase again, but there are sections of the analysis which suggest that this relationship is not always statistically significant for example from both periods 2-4 and beyond period 6, the confidence interval is on both ends of 0. As the results of the impulse response on CPI exchange rates demonstrate both statistically significant and statistically insignificant relationships, it is inconclusive to note the degree of the relationship. The final variable of interest in the analysis is the central bank rate, which upon the initial visual inspection was one of the candidates for a non-causal relationship, and indeed the impulse response functions suggest that this relationship is not statistically significant. To confirm the interpretations of the impulse responses, I conferred with results received after conducting the Granger causality test. The results of the test can be seen in Figure 4.

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	LIQ, EX USD GOLD_x	AVG CF PER USD_x	EX RATE, CPI ADJ_x	CB Rate_x	LOG COB_x
LIQ, EX USD GOLD_y	1.0000	0.4760	0.6350	0.3856	0.3202
AVG CF PER USD_y	0.2186	1.0000	0.1576	0.0388	0.3543
EX RATE, CPI ADJ_y	0.0480	0.0746	1.0000	0.1216	0.0434
CB Rate_y	0.9383	0.0004	0.0776	1.0000	0.1230
LOG COB_y	0.2316	0.0035	0.0161	0.1280	1.0000

Figure 4: Granger causality test results of time-series stationary variables.

The results of the Granger causality test confirm the results of the impulse response analysis demonstrating that the only causal relationship is between log cobalt prices and the CPI adjusted exchange rates. The result is consistent with views found in other pieces of the academic literature[1]. The other results yielded mixed results in review, as it would be expected for the rate of the Congolese Franc to the USD to move similarly to the exchange rate bundle, however the strength of the USD ties to various extemporaneous variables in the world economy which may result in a relationship widely independent of the relationship of both the Congolese Franc and cobalt prices. One question that I had regarding the viability of these results was how the readings of cobalt price relationships compare to a reading of a broad index of metal commodity prices. The Democratic Republic of Congo, while heavily ingrained economically in the export of cobalt products, also is heavily reliant on copper representing

[1] Pinshi (2018), Pederson (2015), Spilimbergo, (1999) all found statistically significant relationships between commodity products and exchange rate data.

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67% of exports, compared with 27% for cobalt products (Observatory of Economic Complexity), therefore I reconducted the analysis using the London Metal Exchange's metal price index, as it captures copper, cobalt, alongside other metal products. The complete outputs are provided in appendix B. of this document; nevertheless, the findings across all variables were shown to be statistically insignificant. In the metal index analysis, the optimal lag term was set at 2, creating a VAR(2) model. After compiling the VAR(2) model and transferring to an impulse response analysis, I visually did not yield any statistically significant relationships with all relationships showing standard deviations on both sides of zero, to confirm the results I confirmed by using the Granger causality test.

The explanations for why the variable relationships were statistically insignificant and did not generate Granger causal results is without a doubt worth exploring further, and while the scope of such an exploration is beyond the research goals of this analysis, potential explanations are explored in the following section alongside potential conflicts that may have occurred during the implementation of the VAR models and impulse response analysis.

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5 Hypotheses and Data Review

The explanation for why cobalt prices are causally related to the CPI-adjusted exchange rates, and not the average rate of Congolese Francs per USD, the total reserve holdings, and the central bank rate can be potentially answered in three ways. The three explanations may either be that the composition of the cobalt mining industry in the Democratic Republic of Congo is affecting the capital returned to the economy, factors of the macroeconomic time series variables are causing them to be independent of what happens on the global commodity markets, or there are potential modeling errors conducted in this analysis.

The first possibility is that the make-up of the cobalt industry in the Democratic Republic of Congo is causing there to be a buffer between the international price impacts and the national macroeconomic variables, this may be because the industry is orchestrated through multinational and foreign-owned mining conglomerates, because of the role of illegal artisanal miners, or because of internal leakages in the formal Congolese mining industry. Currently, in the Democratic Republic of Congo, the largest mining operations are foreign-owned with the Swiss-owned company Glencore and the Chinese-owned China Molybedenum Co. Ltd, controlling 18.7% and 8.9% of the global production share in 2020 (Erickson 2022), further internationalization of the cobalt industry is demonstrated by the statistic that out of the 19 operating cobalt mines in the Democratic Republic of Congo, 15 are Chinese-owned (DeGeurin 2021). Typically, the large presence of international firms operating in a country does not preface substantial lost revenues to the country's economy, however in recent years after the election of President Tshisekedi legal proceedings have brought to light large-scale abuses in the Congolese mining industry including missing revenues funds stemming across both national and international partners, underpayment of local workers by their firms, and international firms conducting non-registered purchases of cobalt from artisanal miners. If legal proceedings are any indication, these abuse cases would be contributions to the buffer

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occurring between the prices of the international market and on-the-ground economic activities that filter towards the macroeconomic profile of the country.

Global Rank	Company	Country of Origin	Attributable Production (tonnes)	Production Value ($M)	Global production share (%)
1	Glencore PLC	Switzerland	25,946	815.28 ($M)	18.708
2	China Molybdenum Co. Ltd.	China	12,349	388.03	8.904
3	Gecamines	DRC	11,693	366.48	8.410
4	Eurasian Group LLP	Luxembourg	10,500 est.	329.93	7.571
5	Shalina Resources Ltd.	United Arab Emirates	6,650 est	208.96	4.795
6	Zhejiang Huayou Cobalt Co. Ltd.	China	5,390 est	169.37	3.886

Figure 5: Top-producing cobalt companies 2020 (data from S&P Global Market Intelligence)

The second contributing factor to the cobalt industry's buffer to the macroeconomy, is that a large subsection of mining activity has been completed in the informal sectors of the economy, which would directly impact the ability of the government to gather revenue, and effectively bolster its central reserve holdings. The informal activity includes artisanal mining operations, which have historically been estimated to equal 20-30% of national cobalt mining returns, and the operators have said to include children, smugglers, or looters of formal corporate mining claims. Understanding the magnitude of the informal economy, at the beginning of 2020, the state-owned mining company Gecamines has begun to establish a monopoly over the informal sector through directly buying all cobalt that is not extracted by industrial operators (Clowes and Kavanaugh 2020). The move has been lauded as an attempt to control the cobalt price on the international market, and according to the time series data in

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the post-2020-time horizon both the cobalt price and the reserve holdings of the DRC have since increased, although a causal relationship to the policy is not directly proven, it is a potential attribution of the new monopoly. The final factor that may influencing our results, is that the cobalt revenues received by the Democratic Republic of Congo are bought through long-term contracts, with one major receiving partner dictating the agreements - China which the world's largest importer of Congolese cobalt. The Congolese Chinese trade relationship is one of the most important drivers of cobalt revenues in the Democratic Republic of Congo, for example, 92.7% of Congolese raw cobalt and 73.3% of cobalt ore were sent to China in 2020 according to the Observatory of Economic Complexity. China has a much larger presence in international cobalt markets than the Democratic Republic of Congo, as it represents both the world's largest refiner of raw cobalt and as the DRC's largest foreign producer of cobalt. Recent developments have seen the Congolese government attempt to renegotiate and legally challenge mining contracts with China over mining rights and revenues, but because of the history of many mining agreements, the global market price may not be a direct factor for some variables of the Congolese economy.

The composition of the cobalt industry does provide convenient and plausible explanations for the results of this analysis, however, the statistically insignificant relationship between the global cobalt price, the Congolese Franc per USD rate, and the central bank rate, may relate more to the metrics of the macroeconomic variables rather than factors of the cobalt industry. As briefly touched upon in Section IV, the rate of the Congolese Franc per US dollar is determined by other macroeconomic variables, these may include factor such as the differentials in inflation, differentials in interest rates, account deficits, rates of public debt, and terms of trade. The factors affecting the direct exchange rate are widely divergent and many are set to meet relative fiscal policy and monetary policy goals, therefore it is assumed that cobalt prices are not a causal factor for measuring the one-to-one exchange rate, but this does

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not explain the previous findings between cobalt prices and the CPI-adjusted exchange rate. One possible explanation for why the relationship between cobalt prices and the CF - USD exchange rate was not causal, is that the rate of the Congolese Franc is pegged to the US dollar, and that the Democratic Republic of Congo is a heavily dollarized country. Currently Congolese bank accounts are denominated in both US dollars and Congolese Francs, and it was not until 2016 that many Congolese governmental accounts and taxes began to be recorded in Congolese Francs.

Regarding the central bank rate, as the country was reeling from record levels of inflation in the aftermath of the Congolese wars of the late 1990s, the interest rate was set at high levels, however, in recent years the rates have come down due to increased levels of political and economic stability, therefore due to the monetary policy influenced by large political and social phenomenon this variable would be understandably independent of global cobalt prices. These explanations are only a few factors that relate to the economic picture in the Democratic Republic of Congo and alongside the factors of the cobalt industry, they serve as considerations for the modeling results.

The final set of considerations stem from the implementation of the VAR model, as the model has been historically critiqued either due to issues with finding the appropriate lag length, entering the statistical series in the model as either lags or differences, or model prediction strategy. In this analysis, by using both the AIC and the BIC tests, I had accounted for potential errors in finding appropriate lag length by selecting the model which gives the smallest error (AIC) and by the process of attempting to find the "real" model (BIC). Using a lag length of six when modeling the cobalt price – macroeconomy relationship seemed to have been an appropriate modeling strategy, primarily because the momentum of the monetary and fiscal policy is expected to be delayed towards an item as historically volatile as the global cobalt price. It is conceded that in this analysis the lag figure was high considering that there

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were only 148 time series observations and that the predictive power may have been hindered due to the loss of degrees of freedom. The number of lag terms is one concern in the analysis, and the second is the choice of variables as this analysis widely ran the risk of confounding variables that would have influenced the final results; therefore, the conclusions of this analysis are truly limited to establishing causal links between cobalt prices and the macroeconomy of the DRC, and relationships regarding increased demand for cobalt and the macroeconomy could not clearly be substantiated. One consideration of how this analysis compared to others in the contemporary literature was that for the Democratic Republic of Congo data high-frequency data was limited for variables that could have enhanced the quality of the analysis such as GDP, inflation rates, local consumer prices, and with such data, the scope of the results could have been both improved and expanded.

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6 Policy Recommendations

Policymakers in the Democratic Republic of Congo have demonstrated the importance cobalt has on the economic future of the country. The importance has been demonstrated by plans to regulate the widely condemned artisanal mining operations and through efforts to renegotiate long-standing mining agreements. While this analysis has demonstrated that the international cobalt market currently has little direct bearing on macroeconomic indicators of the country, there are policy reforms that can allow the country to receive more cobalt revenues as prices begin to rise internationally.

Reforms to the industry can allow the country to bolster the standing of their national currency, the Congolese Franc. The Congolese Franc was widely devaluated in the aftermath of the Congolese wars of the late 1990s and early 2000s and has struggled to regain its footing. The currency has devalued to the point where the financial institutions and the national government have supported de-facto dollarization through bank capitalization and financial accounting regulations. One proposition to bolster the national currency is to have more cobalt contracts denominated in Congolese Francs or to have international mining companies agree that a percentage of earnings be provided in Congolese Francs. With greater usage of the local currency, the fiscal and monetary officials will have more opportunities to influence consumer spending and economic activity and will have greater control over the competitiveness of their exports through currency devaluation.

The second policy proposition is that the country renegotiates the terms of long-standing mining agreements with international firms so that the country would receive additional tax and wage revenues if the price of cobalt on the international market increases above an agreed threshold value. It could be argued that the Congolese should allow greater shares of cobalt to be sold on the open international market, but this would present vulnerabilities for the industry in price drops and fluctuations effectively presenting fiscal authorities with vulnerabilities in

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both medium-term and long-term financial planning. The most advantageous agreements for the national interest would set a price floor for the cobalt sold while having a floating rate set above a negotiated threshold value. By setting a price floor in any cobalt agreement the authorities could account for a minimum of revenue streams.

Further improvements can be made to the Congolese cobalt industry through improving national capacities and directly employing artisanal miners. In the cobalt-producing areas of the country, illicit and independent mining work often reaps greater economic benefits than the formalized sectors of the economy. To prevent leakages of cobalt supplies, the Congolese government has begun to regulate and monopolize the artisanal mines, but in order to maintain social and economic stability monopolization must be complemented with economic incentives that are at or near levels individuals were previously receiving in the illicit market. To reach these goals, the Congolese must expand its mining sector to include refining capabilities, as refineries would both enhance the local economy and would allow the nation to negotiate with more international buyers. As the Congolese mining sector is widely dependent on Chinese refineries' capabilities and demand, the miners lose opportunities to sell to the highest international bidder, especially in the context of more companies entering both the electric vehicle and lithium-ion battery industries. Furthermore, if the Congolese were to effectively refine cobalt, they would diversify their geopolitical risk profile, as industries in China face greater regulatory scrutiny domestically and abroad.

The final recommendation would be that the Congolese government take a counter-cyclical fiscal policy approach with any increased revenue streams from the cobalt sector. The counter-cyclical approach would allow the government to support economic downturn periods and could be effectively complemented with long-term investments in education, infrastructure, and environmentally conscious programs that would allow for long term endowments in

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resource wealth that the Congo is capable of receiving from both its mining industry and its natural asset sector.

Ultimately any hopes of policy implementation will rely on the Congolese's ability to regulate and enforce such programs. Historically, the country has been plagued by events of colonization, authoritarianism, corruption, warfare, and economic mismanagement, therefore as the new political regime has had relative stability in the country taking opportunities to regain economic control and begin economic development programs will be critical for the country's long-term financial security. To support economic development in the DRC greater transparency is required in all sectors of the economy, but most importantly in the internationalized and lucrative mining sector, this can easily be done through regular data reporting to both international and national economic offices.

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7 Conclusion

Inspired by the International Energy Agency's projections that the demand for EVs is expected to rise approximately 36% annually over the next ten years, and that the minerals needed for producing lithium-ion batteries to power EVs are set to be in high demand, this analysis had sought to find the relationship between international cobalt prices set on the London Metal Exchange and the Democratic Republic of Congo's macroeconomic indicators. The Democratic Republic of Congo was chosen as the country of interest for this analysis due to its geological endowment as the largest producer of cobalt in the world, and the variables chosen for analysis included macroeconomic variables such as - the amount of international liquidity and total reserve holdings (non-denominated in gold and USD), the exchange rate of the domestic currency per USD, the real effective exchange rate (based on CPI), and the central bank rate. As the existing academic literature has modeled the relationship between commodity dependent nations' economic indicators and commodity prices through VAR models effectively transforming them into impulse response functions, this paper has built on existing academic trends and implemented similar modeling to evaluate the relationship between cobalt prices and Congolese economic indicators.

To implement a VAR model, this analysis began with evaluating the stationarity of the variables both through visual inspections of the time-series data and through the Augmented Dickey-Fuller test. The dataset was found to be stationary after the cobalt price data was logarithmically transformed and after the optimal integration order was found in first differences. With the stationary data, I had proceeded to find the optimal lag order which was set at six after I had evaluated the AIC, the BIC, and the visual representation of the time series. Once the stationarity and the optimal lag order were set, I generated a VAR(6) model, and subsequent forecast variables, and used these models to generate the impulse response function of logarithmic cobalt prices on the economic variables. The results for logarithmic cobalt prices

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on the international liquidity and total reserves, the local currency per USD rate, and the central bank rate were all statistically insignificant as the projections had standard deviations on both sides of zero, meaning that the response could not conclusively be determined either in magnitude or direction. One statistically significant relationship was the impulse response of logarithmic cobalt prices on the real effective exchange rates, but this relationship was not statistically significant across all time periods, making an interpretation difficult to achieve. The results of the impulse response analysis were followed by the Granger causality test, which confirmed that the logarithmic cobalt prices only had a Granger causal relationship with the real effective exchange rates.

The results of the modeling were largely inconclusive in evaluating a relationship between cobalt prices and macroeconomic variables, and while the results were consistent with findings in the academic literature, this report provided hypotheses for independent reasoning as to why cobalt prices were not a strong indicator despite its large export profile in the Congolese economy. The hypotheses varied from the composition of foreign firms and independent artisanal miners in the cobalt industry, to large macroeconomic phenomena such as policy goals of the central Congolese authorities. However, without more granular data and transparency these hypotheses were largely speculative in nature.

While contributing to the academic literature of modeling commodity prices and macroeconomic variables, this paper can be said to have provided more questions than answers on the theme. The hopes of this author in completing this analysis is that this analysis may be revisited and that with a new political administration and new regulatory rules in the DRC's cobalt industry that more data becomes available for future economic analyses and that the country can benefit from the opportunities presented by the world's transition to more sustainable technologies.

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Appendix A.

```
Augmented Dickey Fuller Test Results

---------------------

Cobalt (USD per Ton)
ADF Statistic: -1.7949046840430731
p-value: 0.38299429480896485

---------------------

International Liquidity, Total Reserves excluding Gold, USD
ADF Statistic: -1.034494635893667
p-value: 0.7404762438789176

---------------------

Domestic Currency per USD
ADF Statistic: -0.10239963617943086
p-value: 0.949198995296965

---------------------

Real Effective Exchange Rate based on CPI
ADF Statistic: -2.0666941282637263
p-value: 0.25811616232330703

---------------------

Central Bank Rate
ADF Statistic: -4.444337672720581
p-value: 0.0002475579757649675
```

Item 1: Augmented Dickey-Fuller test results, variables in stationary format

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Variable	**Integration Order**	**Transformation**
Cobalt (USD per Ton)	I(1)	Logarithmic
International Liquidity, Total Reserves excluding Gold, USD	I(1)	None
Domestic Currency per USD	I(1)	None
Real Effective Exchange Rate based on CPI	I(1)	None
Central Bank Rate	I(1)	None

Item 2: Variable transformations

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```
Augmented Dickey Fuller Test Results

---------------------

Log(Cobalt USD per Ton)
ADF Statistic: -2.221321661501082
p-value: 0.1985981278744698

---------------------

Log(Cobalt USD per Ton)
ADF Statistic: -3.0169471496893956
p-value: 0.03334177421291004

---------------------

International Liquidity, Total Reserves excluding Gold, USD
ADF Statistic: -5.835997154868096
p-value: 3.8753859887261e-07

---------------------

Domestic Currency per USD
ADF Statistic: -3.8401905243999868
p-value: 0.002521867319119716

---------------------

Real Effective Exchange Rate based on CPI
ADF Statistic: -8.625595043600754
p-value: 5.942416575421374e-14

---------------------

Central Bank Rate
ADF Statistic: -5.830029690594425
p-value: 3.995147680104146e-07
```

Item 3: Augmented Dickey-Fuller results – logarithmic + first differences

```
Lag Order = 1
AIC :  13.931015060203409
BIC :  14.546891006911114
FPE :  1122704.9609184857
HQIC:  14.18126628813741

Lag Order = 2
AIC :  13.827369138592893
BIC :  14.96167282940317
FPE :  1013439.1394469672
HQIC:  14.28828615339692

Lag Order = 3
AIC :  14.044003780684504
BIC :  15.701539238172565
FPE :  1262631.054907581
HQIC:  14.71754681901261

Lag Order = 4
AIC :  14.03492275391626
BIC :  16.220569521860856
FPE :  1259024.5224154247
HQIC:  14.923080882053187

Lag Order = 5
AIC :  14.010393673132377
BIC :  16.729108465679623
FPE :  1241375.3326743538
HQIC:  15.11518533752417

Lag Order = 6
AIC :  13.933693003332746
BIC :  17.190511399793046
FPE :  1168212.8500677187
HQIC:  15.257166592961536

Lag Order = 7
AIC :  14.05182198828052
BIC :  17.851860175068467
FPE :  1345368.968198741
HQIC:  15.5960564091045

Lag Order = 8
AIC :  14.141980138178708
BIC :  18.49043669946296
FPE :  1520180.7224627896
HQIC:  15.909085399856576

Lag Order = 9
AIC :  13.992281675168392
BIC :  18.894439433857947
FPE :  1366482.7669917915
HQIC:  15.984399490284815

Lag Order = 10
AIC :  14.085548271612605
BIC :  19.5467761823677
FPE :  1587760.4724663466
```

```
HQIC:  16.304852667617734

Lag Order = 11
AIC :  14.269715985535512
BIC :  20.29547108155596
FPE :  2054813.6392120945
HQIC:  16.718413929607102

Lag Order = 12
AIC :  14.059462680450302
BIC :  20.65529207586096
FPE :  1830179.233009576
HQIC:  16.739794717481264

Lag Order = 13
AIC :  13.698886825249005
BIC :  20.870429774972152
FPE :  1439119.2275417177
HQIC:  16.61312772915639

Lag Order = 14
AIC :  13.527283090152295
BIC :  21.280273109229277
FPE :  1411489.0736647097
HQIC:  16.6777425286954

Lag Order = 15
AIC :  13.236711103301998
BIC :  21.576978147702285
FPE :  1279669.533883861
HQIC:  16.625734316587508

Lag Order = 16
AIC :  13.123055848811697
BIC :  22.056528559846395
FPE :  1457853.6289866976
HQIC:  16.753024341652196

Lag Order = 17
AIC :  12.816287594514796
BIC :  22.348995609053702
FPE :  1464186.6960814702
HQIC:  16.689619842793622

Lag Order = 18
AIC :  12.12821517438812
BIC :  22.266291503164883
FPE :  1098668.1816258943
HQIC:  16.247367345567966

Lag Order = 19
AIC :  11.088077518518702
BIC :  21.83776099489763
FPE :  656675.4813182995
HQIC:  15.455544206413451

Lag Order = 20
AIC :  10.15740704839845
```

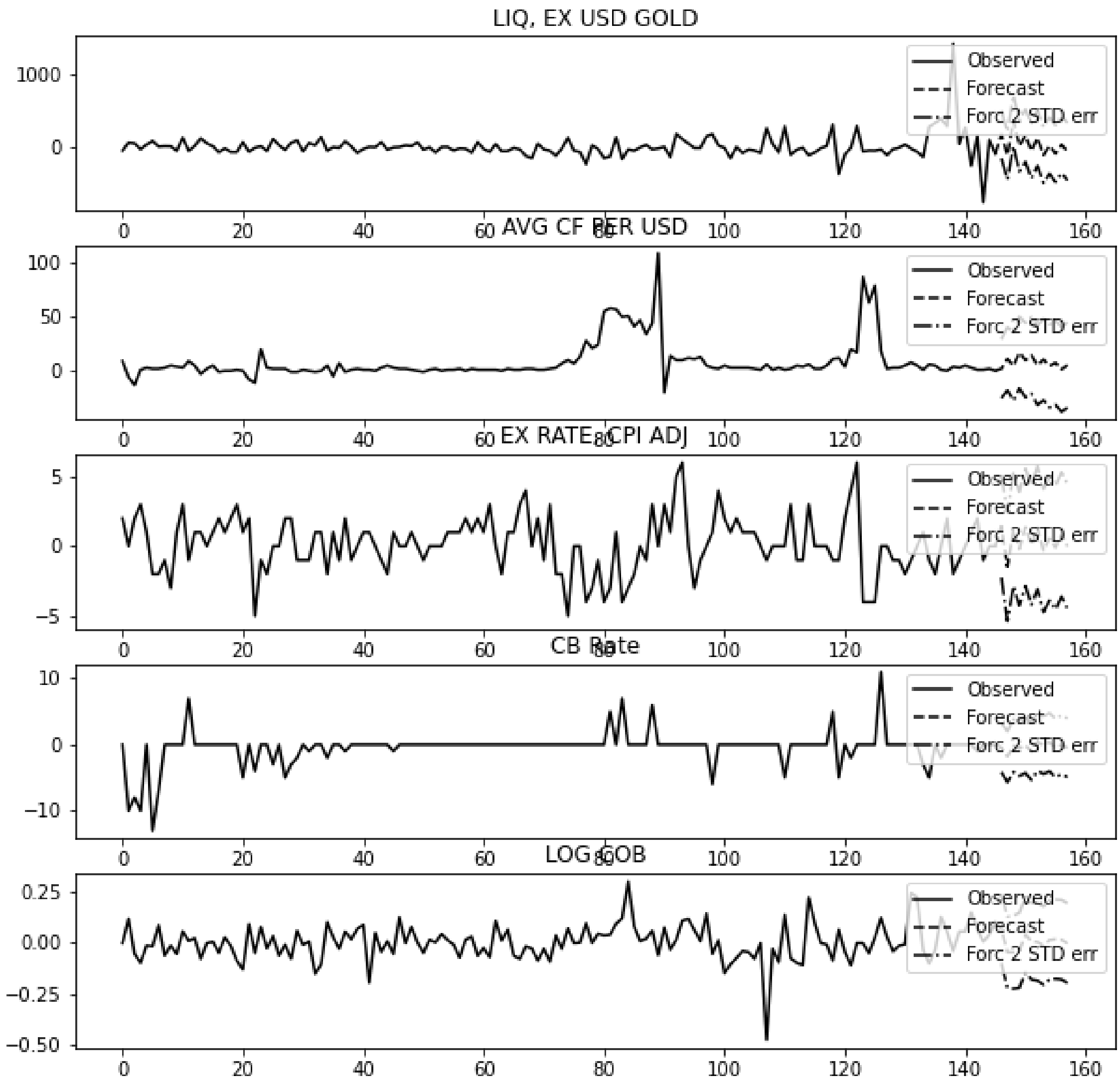
```
BIC :  21.525044850069055
FPE :  525394.6616257441
HQIC:  14.775722022307288

Lag Order = 21
AIC :  9.364182850801111
BIC :  21.356233096962868
FPE :  643113.5023188023
HQIC:  14.235919819080578

Lag Order = 22
AIC :  7.532983603989138
BIC :  20.156018030689104
FPE :  467218.11541462905
HQIC:  12.66075699211215

Lag Order = 23
AIC :  4.361762237872089
BIC :  17.622468954262352
FPE :  291744.8632499964
HQIC:  9.748227980992857
```

Item 4: Lag order selection - AIC and BIC selection



Item 5: Forecast results

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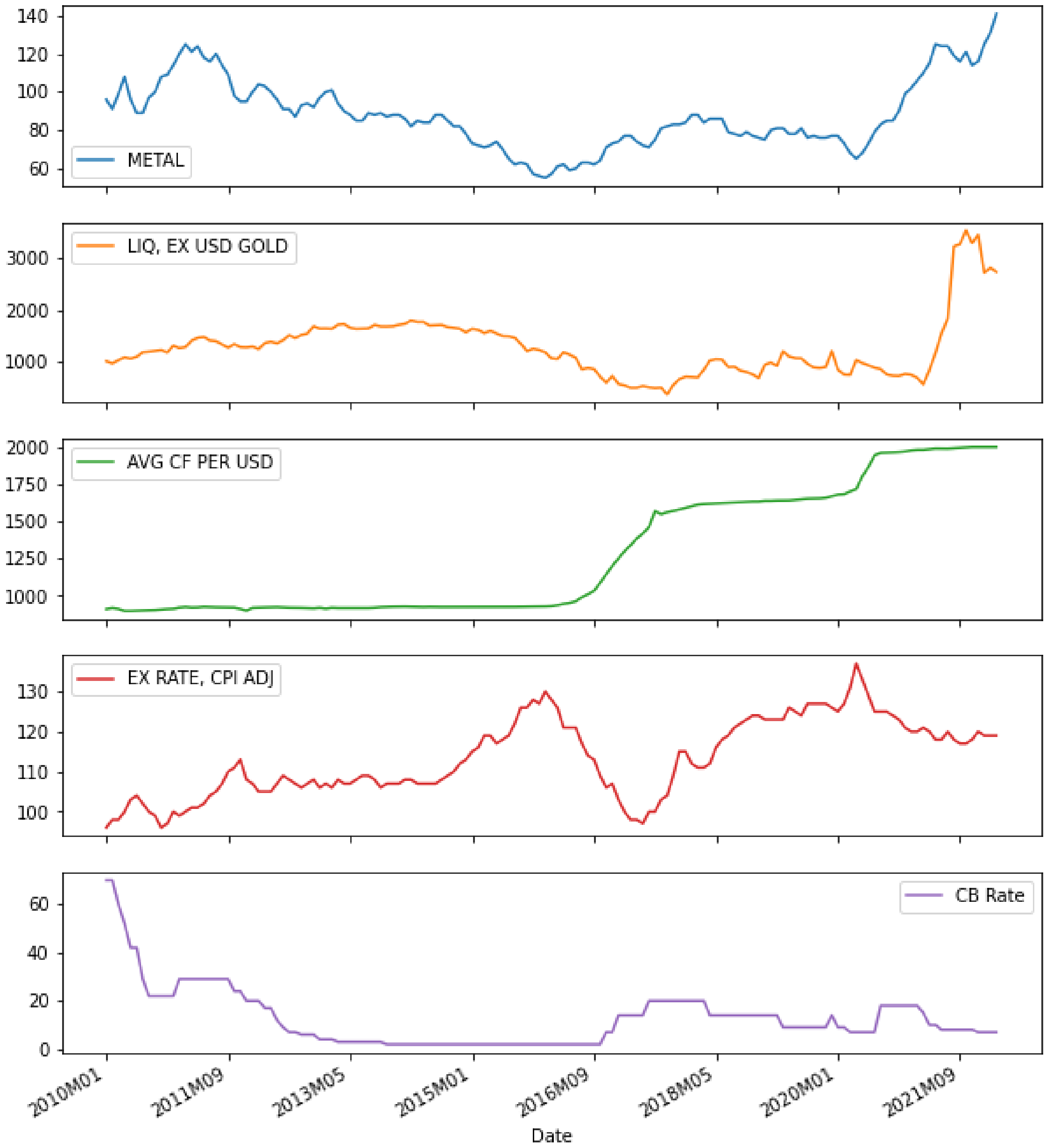
Appendix B.



Item 1: Visual inspection – commodity metal exchange prices and DRC macroeconomic variables

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```
Augmented Dickey Fuller Test Results

---------------------

Commodities Metal Index
ADF Statistic: -0.48205550706904465
p-value: 0.895470930732924

---------------------

International Liquidity, Total Reserves excluding Gold, USD
ADF Statistic: -1.034494635893667
p-value: 0.7404762438789176

---------------------

Domestic Currency per USD
ADF Statistic: -0.10239963617943086
p-value: 0.949198995296965

---------------------

Real Effective Exchange Rate based on CPI
ADF Statistic: -2.0666941282637263
p-value: 0.25811616232330703

---------------------

Central Bank Rate
ADF Statistic: -4.444337672720581
p-value: 0.0002475579757649675
```

Item 2: Augmented Dickey-Fuller results – Stationary

Variable	Integration Order	Transformation
London Metal Exchange's commodities metal index prices	I(1)	Logarithmic
International Liquidity, Total Reserves excluding Gold, USD	I(1)	None
Domestic Currency per USD	I(1)	None
Real Effective Exchange Rate based on CPI	I(1)	None
Central Bank Rate	I(1)	None

Item 3: Variables – Transformations

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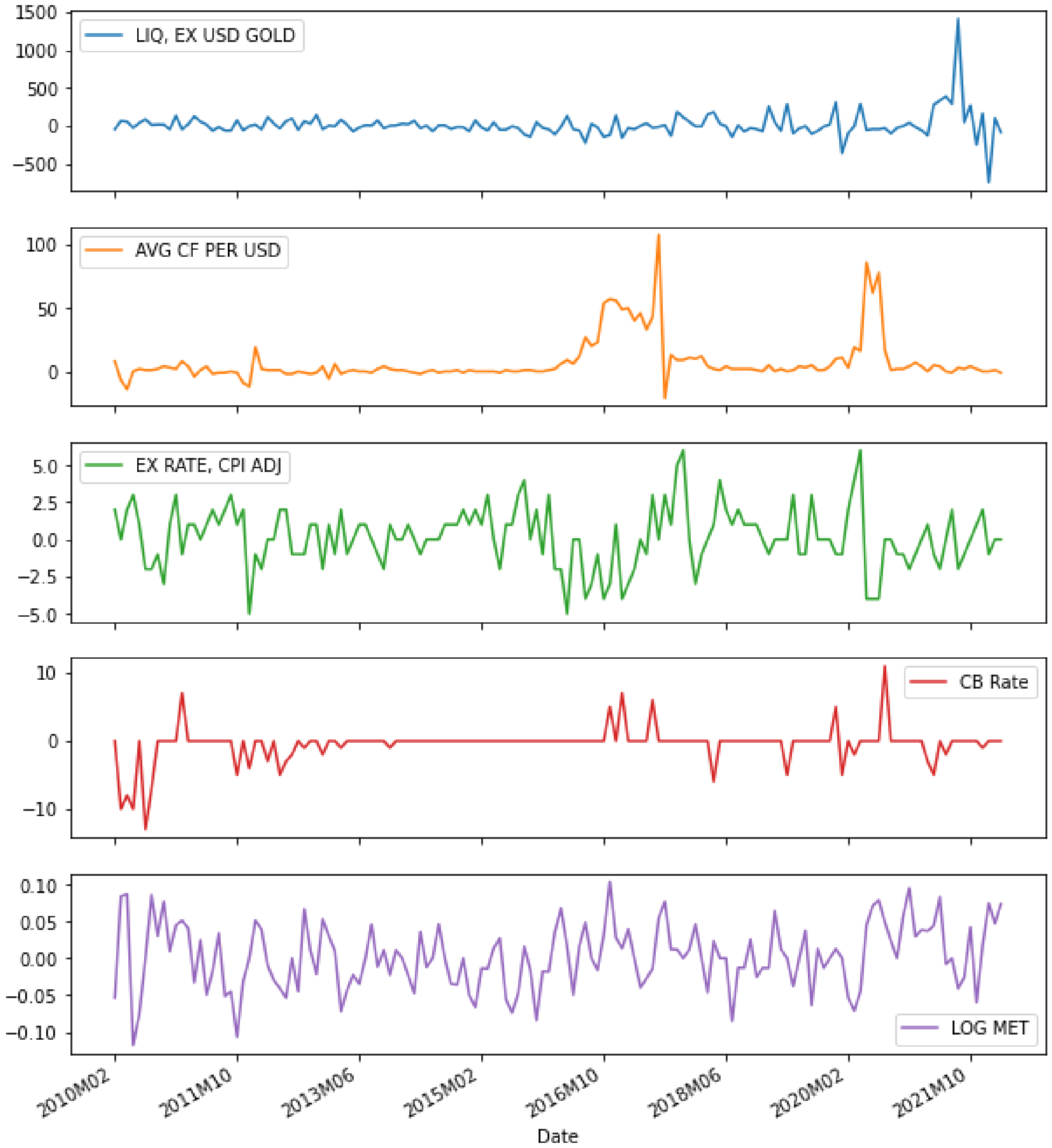

Item 4: Visual Inspection – Transformed Variables

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```
Augmented Dickey Fuller Test Results

---------------------

Log Metal Index
ADF Statistic: -0.8826448096390046
p-value: 0.7936339924095066

---------------------

Log Metal Index
ADF Statistic: -8.635052553496967
p-value: 5.620155479123332e-14

---------------------

International Liquidity, Total Reserves excluding Gold, USD
ADF Statistic: -5.835997154868096
p-value: 3.8753859887261e-07

---------------------

Domestic Currency per USD
ADF Statistic: -3.8401905243999868
p-value: 0.002521867319119716

---------------------

Real Effective Exchange Rate based on CPI
ADF Statistic: -8.625595043600754
p-value: 5.942416575421374e-14

---------------------

Central Bank Rate
ADF Statistic: -5.830029690594425
p-value: 3.995147680104146e-07
```

Item 5: Augmented Dickey-Fuller results – Logarithmic + First Differences

```
Lag Order = 1
AIC :  12.300425360369783
BIC :  12.916301307077488
FPE :  219841.4261784943
HQIC:  12.550676588303784

Lag Order = 2
AIC :  12.135730714764923
BIC :  13.2700344055752
FPE :  186693.1743417233
HQIC:  12.59664772956895

Lag Order = 3
AIC :  12.317386025821028
BIC :  13.974921483309089
FPE :  224603.1813606134
HQIC:  12.990929064149134

Lag Order = 4
AIC :  12.159098219616277
BIC :  14.344744987560873
FPE :  192918.5303500772
HQIC:  13.047256347753203

Lag Order = 5
AIC :  12.145589004412164
BIC :  14.864303796959412
FPE :  192321.89688940786
HQIC:  13.25038066880396

Lag Order = 6
AIC :  12.241362953290345
BIC :  15.498181349750645
FPE :  215056.4025983876
HQIC:  13.564836542919133

Lag Order = 7
AIC :  12.318771838849317
BIC :  16.118810025637263
FPE :  237786.55196413703
HQIC:  13.863006259673297

Lag Order = 8
AIC :  12.36719201407524
BIC :  16.715648575359495
FPE :  257700.06735454797
HQIC:  14.13429727575311

Lag Order = 9
AIC :  12.178079185466807
BIC :  17.08023694415636
FPE :  222692.72456942944
HQIC:  14.17019700058323

Lag Order = 10
AIC :  12.234411299012793
BIC :  17.69563920976789
FPE :  249371.26793351662
```

```
HQIC:  14.45371569501792

Lag Order = 11
AIC :  12.36117824216933
BIC :  18.386933338189777
FPE :  304722.85547341994
HQIC:  14.80987618624092

Lag Order = 12
AIC :  12.110618650775884
BIC :  18.70644804618654
FPE :  260688.22495814174
HQIC:  14.790950687806845

Lag Order = 13
AIC :  11.722496645609759
BIC :  18.894039595332906
FPE :  199416.6547290444
HQIC:  14.636737549517143

Lag Order = 14
AIC :  11.568882475324486
BIC :  19.321872494401468
FPE :  199138.36644871655
HQIC:  14.719341913867591

Lag Order = 15
AIC :  11.267373099183974
BIC :  19.60764014358426
FPE :  178576.86821999997
HQIC:  14.656396312469482

Lag Order = 16
AIC :  11.101374399040047
BIC :  20.034847110074743
FPE :  193067.34504861472
HQIC:  14.731342891880544

Lag Order = 17
AIC :  10.801623944626737
BIC :  20.33433195916564
FPE :  195271.6295146465
HQIC:  14.674956192905563

Lag Order = 18
AIC :  10.232122374642085
BIC :  20.370198703418847
FPE :  164969.5945592552
HQIC:  14.351274545821932

Lag Order = 19
AIC :  9.580679171934626
BIC :  20.330362648313553
FPE :  145444.06936456758
HQIC:  13.948145859829374

Lag Order = 20
AIC :  9.016693236845025
```

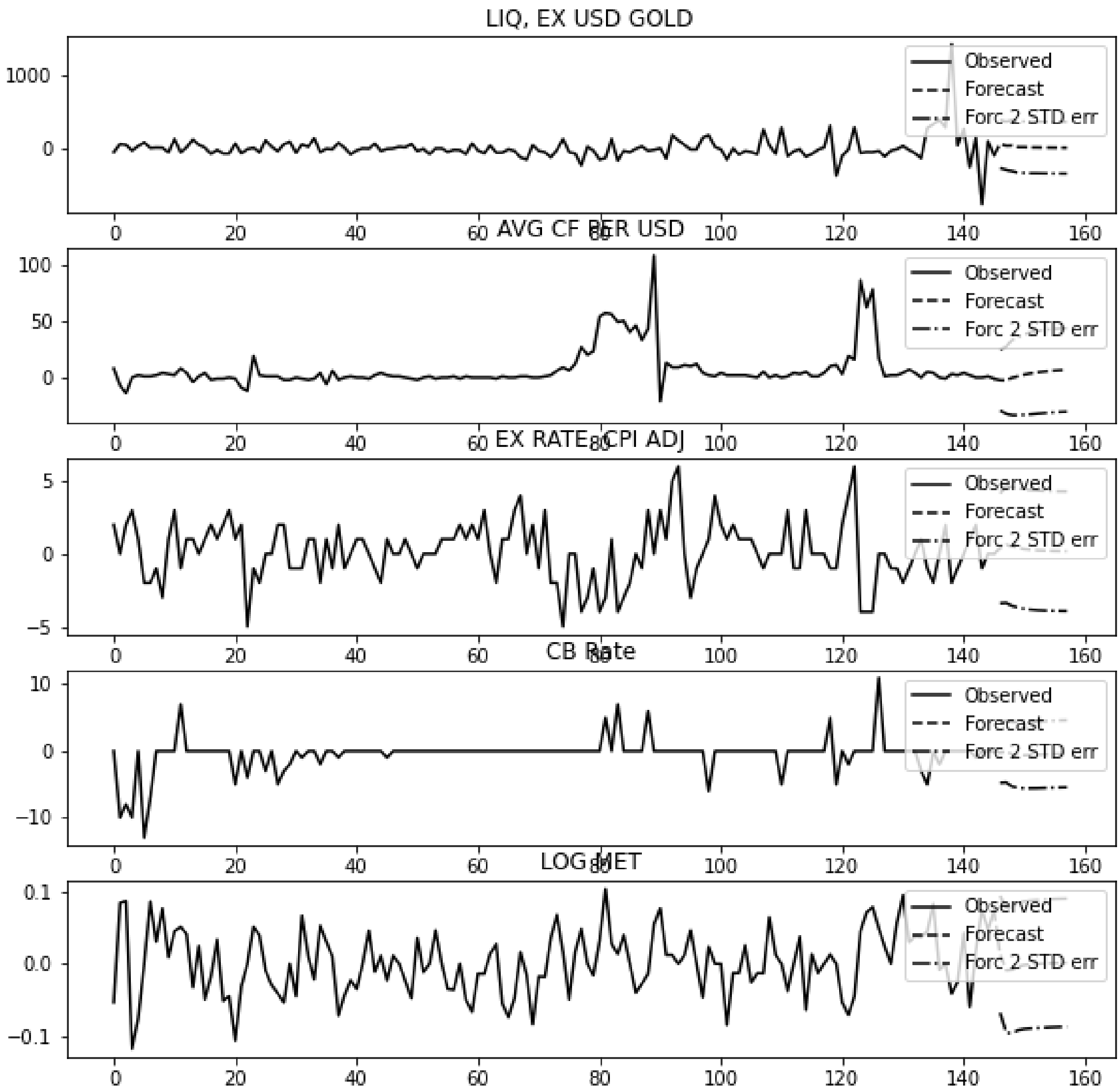
```
BIC :  20.38433103851563
FPE :  167911.30692996937
HQIC:  13.635008210753863

Lag Order = 21
AIC :  7.281463523934107
BIC :  19.273513770095864
FPE :  80126.12067518018
HQIC:  12.153200492213577

Lag Order = 22
AIC :  5.023459877041059
BIC :  17.646494303741022
FPE :  37988.08197308386
HQIC:  10.151233265164072

Lag Order = 23
AIC :  0.82642852818182
BIC :  14.087135244572082
FPE :  8504.079203205658
HQIC:  6.212894271302588
```

Item 6: Lag order selection – AIC and BIC selection



Item 7: Forecast results

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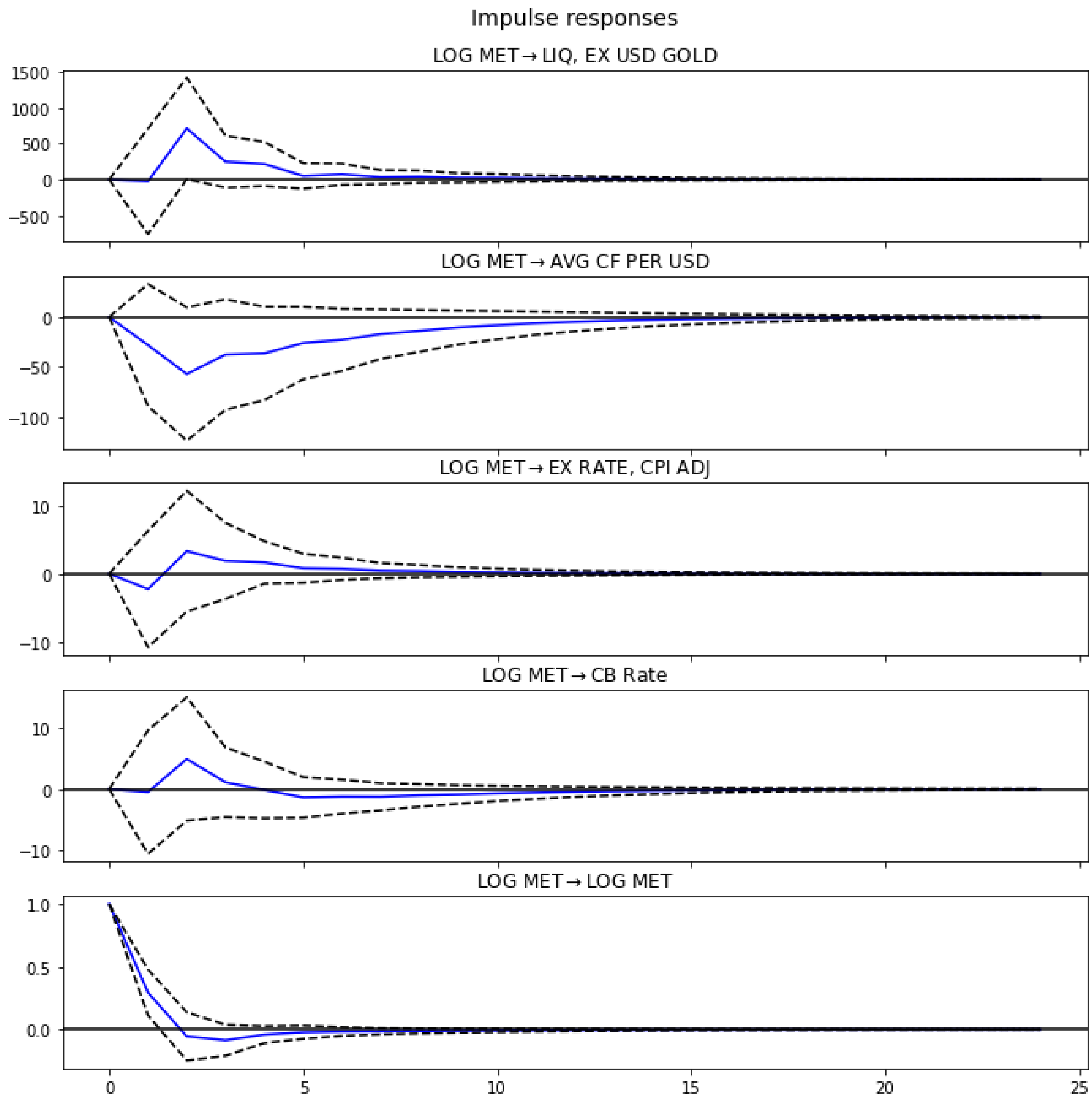

Item 8: Impulse response function of LOG metal prices

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	LIQ, EX USD GOLD_x	AVG CF PER USD_x	EX RATE, CPI ADJ_x	CB Rate_x	LOG MET_x
LIQ, EX USD GOLD_y	1.0000	0.4760	0.8411	0.3856	0.1544
AVG CF PER USD_y	0.7899	1.0000	0.5058	0.0502	0.2421
EX RATE, CPI ADJ_y	0.4026	0.2217	1.0000	0.1216	0.5330
CB Rate_y	0.9661	0.0004	0.1498	1.0000	0.1666
LOG MET_y	0.8235	0.0056	0.2304	0.4955	1.0000

Item 9: Granger causality test results

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Bibliography

Basov, Vladimir. 2022. "The World's Largest Cobalt Producing Countries in 2021 - Report." Kitco News. February 2, 2022. https://www.kitco.com/news/2022-02-02/Global-cobalt-production-hits-record-in-2021-as-mined-cobalt-output-in-DR-Congo-jumps-22-4.html.

Burton, Mark. 2019. "How the Cobalt Market Fell Victim to Allure of Electric Cars." *Bloomberg.com,* March 1, 2019. https://www.bloomberg.com/news/articles/2019-03-01/how-the-cobalt-market-fell-victim-to-the-allure-of-electric-cars.

Castelvecchi, Davide. 2021. "Electric Cars and Batteries: How Will the World Produce Enough?" *Nature* 596 (7872): 336–39. https://doi.org/10.1038/d41586-021-02222-1.

Chan, Kalok, Yiuman Tse, and Michael Williams. 2009. "The Relationship between Commodity Prices and Currency Exchange Rates." *Commodity Prices and Markets*, May, 47–76. https://doi.org/10.7208/chicago/9780226386904.003.0003.

Chuku, Chuku, Anthony Simpasa, and Jacob Oduor. 2018. "Macroeconomic Consequences of Commodity Price Fluctuations in African Economies." *African Development Review* 30 (4): 329–45. https://doi.org/10.1111/1467-8268.12354.

Clowes, William, and Michael Kavanaugh. 2020. "DRC Moves to Monopolise about 25 Percent of All Cobalt Exports." Www.aljazeera.com. Al Jazeera. January 30, 2020. https://www.aljazeera.com/economy/2020/1/30/drc-moves-to-monopolise-about-25-percent-of-all-cobalt-exports.

"Congo, Democratic Republic - Currency/Money | Privacy Shield." n.d. Www.privacyshield.gov. https://www.privacyshield.gov/article?id=Congo-Democratic-Republic-Currency-Money.

Deaton, Angus, and Ron Miller. 1995. "INTERNATIONAL COMMODITY PRICES, MACROECONOMIC PERFORMANCE, and POLITICS in SUB-SAHARAN AFRICA." *PRINCETON STUDIES in INTERNATIONAL FINANCE,* no. 79 (October). https://rpds.princeton.edu/sites/g/files/toruqf1956/files/media/deaton_miller_international_commodity_prices_macroeconomic_performance_and_politics_puisf1995.pdf.

DeGeurin, Mack. 2021. "Cobalt Is the New Oil." Gizmodo. November 21, 2021. https://gizmodo.com/cobalt-is-the-new-oil-1848105024.

CEU eTD Collection

"Democratic Republic of the Congo (COD) Exports, Imports, and Trade Partners | OEC." n.d. OEC - the Observatory of Economic Complexity. Accessed June 4, 2022. https://oec.world/en/profile/country/cod?compareExports0=comparisonOption5&yearSelector1=exportGrowthYear21.

Department of Operations Europe, Africa and Australasia, INTERNATIONAL BANK FOR RECONSTRUCTION AND DEVELOPMENT. 1957. "THE ECONOMY of the BELGIAN CONGO." World Bank. World Bank. November 19, 1957. https://documents1.worldbank.org/curated/en/261281468019142230/pdf/multi0page.pdf.

Erickson, Camille. 2022. "Cobalt Miners Seeking to Expand in Congo Face Human Rights Accusations." Www.spglobal.com. S&P Global Market Intelligence. February 18, 2022. https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/cobalt-miners-seeking-to-expand-in-congo-face-human-rights-accusations-68726919.

Larsen, Nicholas. 2019. "Why Have Cobalt Prices Crashed." International Banker. July 31, 2019. https://internationalbanker.com/brokerage/why-have-cobalt-prices-crashed/.

Munshi, Neil. 2020. "Belgium's Reckoning with a Brutal History in Congo." *The Financial Times,* November 13, 2020. https://www.ft.com/content/a17b87ec-207d-4aa7-a839-8e17153bcf51.

Ndikumana, Leonce, and James Boyce. 1998. "Congo's Odious Debt: External Borrowing and Capital Flight in Zaire." *Development and Change* 29 (2): 195–217. https://doi.org/10.1111/1467-7660.00076.

Pedersen, Michael. 2018. "The Impact of Commodity Price Shocks in a Copper-Rich Economy: The Case of Chile." *Empirical Economics* 57 (4): 1291–1318. https://doi.org/10.1007/s00181-018-1485-9.

Pinshi, Christian. 2018. "Macroeconomic Effects of Falling Commodity Price: Evidence from Democratic Republic of the Congo." *Munich Personal RePEc Archive*. University Library of Munich, Germany. https://mpra.ub.uni-muenchen.de/101068/1/MPRA_paper_101068.pdf.

Spilimbergo, Antonio. 1999. *Copper and the Chilean Economy, 1960–98*. International Monetary Fund.

United Nations Conference on Trade and Development. 2019. "State of Commodity Dependence 2019 | UNCTAD." Unctad.org. United Nations Conference on Trade and Development. May 19,

CEU eTD Collection

2019. https://unctad.org/webflyer/state-commodity-dependence-2019.

United States Geological Survey. 2020. "COBALT - Mineral Commodity Summaries." *USGS.gov*. U.S. Geological Survey. https://pubs.usgs.gov/periodicals/mcs2020/mcs2020-cobalt.pdf.

"Vector Autoregression | Encyclopedia.com." n.d. Www.encyclopedia.com. International Encyclopedia of the Social Sciences. https://www.encyclopedia.com/social-sciences/applied-and-social-sciences-magazines/vector-autoregression.

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