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The role of economic growth and governance on mineral rents in main critical minerals countries

Junguo Shi\textsuperscript{a,b}, Yang Liu\textsuperscript{b}, Bert M. Sadowski\textsuperscript{c}, David Alemzero\textsuperscript{b}, Shanshan Dou\textsuperscript{d,*}, Huaping Sun\textsuperscript{b,c}, Sobia Naseem\textsuperscript{a}

\textsuperscript{a} Institute of Industrial Economics, Jiangsu University, Xuefu Road 301, Zhenjiang, 212012, Jiangsu, China
\textsuperscript{b} School of Finance and Economics, Jiangsu University, Xuefu Road 301, Zhenjiang, 212012, Jiangsu, China
\textsuperscript{c} Institute of Industrial Economics, Jiangsu University, Xuefu Road 301, Zhenjiang, 212012, Jiangsu, China
\textsuperscript{d} Sustainability Management Program, Inha University, 100 Inha-ro, Michuhol-gu, Incheon, 22212, South Korea

\textsuperscript{*} Corresponding author.
E-mail addresses: jshi@ujs.edu.cn (J. Shi), 2201153923@qq.com (Y. Liu), B.M.Sadowski@tue.nl (B.M. Sadowski), awelingazure@gmail.com (D. Alemzero), shansdou@inha.edu.cn (S. Dou), shp@ujs.edu.cn (H. Sun), sobiasalamat4@gmail.com (S. Naseem).

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ABSTRACT
As the importance of critical minerals in facilitating the energy transition has grown, the present discussion has switched to examining 18 leading mineral resource-endowed countries for their economic and governance performance from 2002 to 2019 by employing a panel random effect model. The findings demonstrate the validity of the Pareto principle when studying mineral rents and economic development. The results confirm that mineral rents are positively related to GDP growth and governance levels measured by control of corruption. Trade volume and renewable energy consumption are also positively associated with mineral rents. The paper sheds some light on the socioeconomic and governance performance of resource-endowed countries. It provides policy suggestions for the development of critical minerals necessary for a sustainable energy transition.

1. Introduction

The mining and minerals industry, responsible for a wide range of activities involving extraction, processing, and distribution of minerals and metals such as coal, iron, copper, gold, silver and diamonds, is one of the sectors with the longest industrial history. It has helped drive the growth of other sectors of the economy. For protracted periods of history, mining and mineral industries played an essential role in supporting national economies. Researchers and governments have recently turned their attention to mining using green technology and the recyclable nature of mineral resources as a result of the growing threat posed by global warming (Adomako and Tran, 2022; Dubinski, 2013). Mineral resources are fundamental to socioeconomic advancement, and national security, and provide the backbone of the physical infrastructure of modern society (Schulz, 2017). Minerals become important as minerals are consumed in enormous proportions and across a large variety of industrial sectors such as telecommunications, mobile phones and computers, renewable energy supply, wind turbine manufacturing and solar panels for mobility in electric vehicles (EVs) (Hayes and McCul lough, 2018).

This study seeks to evaluate the performance of the major mineral-endowed countries in the world that provide vital input to the energy transition. By identifying essential Critical Minerals (CMs) for the energy transition and providing an empirical evaluation of economic, environmental, and regulatory factors impacting the development of these CMs, this paper is aimed at advancing our understanding of the role of CMs in facilitating a successful energy transition. In this context, it becomes essential that primary nonfuel mineral supplying countries pay closer attention to the environmental and social ramifications of mineral development for their local communities and on the global scale. The joint objective of achieving better economic and environmental performance must be pursued in these countries to derive maximum economic value, achieve a higher ecological quality, and have a better regulatory environment. These minerals have been considered indispensable for the energy transition (Patil et al., 2022). Problems with the energy transition can emerge in case the critical impact of these minerals will be ignored. The criticality of these minerals has been defined by the European Commission and is characterized according to fourteen different categories that are economically relevant to the EU. The reasons for this critical impact across these categories are related to the
substantial increase in supply risk.

With increased competition for these minerals, higher environmental costs can be anticipated. Due to a very high supply risk, for some of these critical minerals such as cobalt and lithium, the demand will be even greater as they provide vital input to the production of batteries or wind turbines. In particular, lithium is considered a mineral with high expectations concerning revenue growth (Gielen and Lyons, 2022), while the demand for copper will increase from about 150 billion USD in 2020 to more than 350 billion USD in 2030. These predictions are in line with research by the IEA (IEA, 2022) which states that the clean energy sector is the main buyer of critical minerals, with a demand of over 40% for copper and rare earth minerals (REE), 60–70% for nickel and cobalt and over 90% for lithium by 2040. However, the global cobalt and nickel, as well as the lithium market, are relatively small. The markets for these minerals are expected to grow shortly. Given these scenarios, it is evident that mineral-endowed countries will reap the maximum economic value from these minerals.

Just a few studies were done at the country level, but hardly any looked across different countries. Therefore, to fill this void, we utilized a combination of panel random effects analysis to examine the role of economic growth and governance on mineral rents in main critical minerals countries. The contribution of this study to the literature on the performance of the main countries controlling mineral minerals is stated below. First, we use the Pareto principle to examine the contribution of economic growth to mineral rents. Some countries have mineral resources that contribute as much as 16.7% (Chile) to GDP but do not derive sufficient economic benefit from this contribution. This is due to the lack of competencies, linkages and the institutional framework that allows for sustainable management of the raw materials sector. In contrast, developed countries with a lower contribution of mineral resources to GDP, like Canada with 15.8%. These countries can realize a higher economic value from mineral development. Another result is that mineral resources provide the technological opportunities for an increase in the deployment of renewable energy by 3.45%, which includes the mining of CMs like copper or lithium as these minerals are responsible for technologies providing high emissions like wind turbines or solar panels. This finding is in line with Srivastava and Kumar (2022) who show that the energy transition is highly dependent on the development of critical minerals. The study provides information on the economic and environmental performance of the leading countries with a controlling stake in critical minerals that are vital for the energy transition. Second, this paper contributes to the recent discussion on the role of governance capability. The management of mineral rents is a significant challenge for governments. The minerals and mining sector involves myriad governance challenges related to price volatility, the number of actors involved, and the sector’s significance. The political state plays a crucial role in the management of mineral rents. For example, the government of Botswana managed a steady, sustained expansion in mineral rents, while the economic policy of its Saudi counterpart lost some coherence. By using control of corruption as a proxy, we confirm that good governance plays a crucial role in the proper distribution of mineral rent.

The remainder of the paper is structured as follows: Section 2 presents a literature review about the role of economic growth and governance on mineral rents. Section 3 discusses the method and data while providing detailed information on the methodological approach implemented. Section 4 contains the analytical findings, and Section 5 summarizes the major argument and provides policy conclusions.

2. Literature review

2.1. The role of economic growth on mineral rents

For centuries, natural resources were believed to be directly linked to development and economic growth. Since the 1950s, however, opposing views, such as the Prebisch-Singer hypothesis, have challenged this traditional idea. This hypothesis suggests that developing countries, which rely heavily on natural resource exports, face declining terms of trade due to the unequal exchange of commodities in global markets. As a result, these countries become dependent on the exports of these resources and vulnerable to price fluctuations in these markets (Caldentey and Vernengo, 2016; Sapsford et al., 1992). These views have contributed to a broader understanding of the challenges facing mineral-endowed developing countries, including the need for diversification of their economies and how sustainable economic growth can be achieved by promoting governance mechanisms that are based on transparency, and accountability and oppose corruption.

As mineral rents can provide a lucrative source of income for those who control access to them, they create incentives for individuals and firms to engage in rent-seeking behavior including corruption, bribery and manipulation of regulations and policies to gain preferential access to these resources. Krieger (1974) coined the term ‘rent seeking’ to address this behavior where economic actors seek to gain a larger share of wealth by manipulating the rules of the market or the political system rather than creating new wealth. To examine the effects of the rent-seeking behavior of elites on economic growth, Sadik-Zada (2023) used a differential game theory model to characterize the interaction between the public and elites in mineral-endowed developing countries. He found that based on the conventional transversality conditions there is a progressive deterioration of social cohesion and institutional quality. Furthermore, he proposed that at the advanced stages of natural resource exploitation, the public and elite seek to maximize short-term personal gains, and thus ultimately hinder economic modernization. In evaluating the effects of natural resource rent on economic growth in some major wealthy economies of the world (5+1 countries (The UK, The USA, Germany, France, China, and Russia), Singh et al. (2023) found a negative relationship for the panel but a different impact on quantiles in each country. The results of their quantile-on-quantile regression showed a positive effect for China and the US for both lower and higher quantiles of natural resources and economic growth. In assessing the impact of green energy and Africa’s natural resource rents on economic growth, Mumuni and Mwimba (2023) found that green energy initially worsens economic growth but later acts as a facilitator of long-term growth. The results of their analysis based on a dynamic panel ARDL model and feasible generalized least square (FGLS) approximators over the period 1990–2020 for 24 African countries showed that the rents from natural resources in Africa have short-run positive effects, but these effects are not significant over the long term. Their research provided evidence for the natural resource course affecting major African countries.

Previous research has shown that resource-endowed countries have rarely been able to use these resources to achieve sustainable development, as the growth of new sectors required less dependence on exhaustible resources and a change in existing linkages across sectors. Few countries have been able to avoid the natural resource curse by carefully promoting new ways of organizing cross-industry connections and avoiding over-specialization in certain sectors (Kaplinsky et al., 2011). Based on resource-intensive industries, laggard countries can catch up with leading nations because these industries present an opportunity for these countries to become technologically active and innovative by accessing, producing, and transforming these resources (Marín et al., 2015). However, to enable this shift towards new sectors, creating links between sectors and within sectors requires more effective management and policies that focus on complementarities depending on existing technological conditions and opportunities (Venable, 2016; Landini and Malerba, 2017). The challenge for multinational enterprises fostering foreign direct investment (FDI) has been engaging in managing and promoting linkage creation in these new sectors (Narula, 2018).

2.2. The role of governance on mineral rents

Scholars have focused on governance and institutional quality as
they relate to the creation and capture of mineral rents. Lane and Tornell (1996) showed that resource-endowed countries have slower growth compared to less resource-endowed countries because rents derived from natural resources, provide incentives for rent-seeking behaviors by the country’s political class. In case the government derives a large share of its earnings from natural rents, the countries’ ruling class should be accountable to citizens and how it is using rents (Moore et al., 2001; Hickey et al., 2023). However, if the ruling class will not be held accountable for how minerals rents are spent, this will not lead to a favorable way of using these rents for economic growth and industrialization of these countries. There is a threat in these resource-endowed countries that mineral rents are becoming detached from economic activities, which might deplete these mineral resources rather quickly to countries that mineral rents are becoming detached from economic activities.

3. Data, variables and methods

3.1. Data and variables

The sample countries are Argentina, Australia, Brazil, Cuba, Chile, China, DRC, Canada, Guatemala, Indonesia, India, Russia, United States, Mexico, Poland, Vietnam, and Zambia, which are the top countries producing critical minerals (i.e., cobalt, copper, lithium, nickel, and rare earth elements) (Leruth et al., 2022). Table 1 shows the top three critical minerals and the countries supplying them. The table sheds some light on the importance of sample selection for this research. Almost all selected countries are included in the top mineral production nations in the world. As depicted in Table 1, the Democratic Republic of Congo is responsible for nearly 70% of cobalt resources in the world, with a cobalt market that grew exponentially, the manufacturing of batteries constitutes less than 30% of cumulative demand in 2000 and jumped to 60% in 2019 (Pommeret et al., 2022), followed by Russia with 6.3%. In comparison, Chile controls more than 28% of the copper supply, followed by Peru and China. On the other hand, Australia controls about 54.2% of global lithium supplies, followed by Chile and China. Indonesia is the world’s leading producer of nickel, with the Philippines and Russia at second and third place. Indonesia also has a large share of the world’s proven nickel reserves. The critical mineral sector is a net benefit of carbon abatement because the sector emits carbon dioxide during the mining of these minerals and metals, as well as these minerals act to reduce carbon dioxide emissions within the larger economy (Leruth et al., 2022).

Data were derived from the World Bank Development Indicator and Governance Indicator. The study period is between 2002 and 2019. The rationale for the choice of the study period is that natural resource exploitation has substantially increased since the 2000s. Table 2 shows the main variables and their definition and measurement. The explained variable is measured by mineral rents over total natural resources rents (MRTN). The explaining variables are GDP growth and control of corruption. GDP growth is measured by an annual percentage growth rate of GDP at market prices based on constant local currency. We use the control of corruption variable to examine its role of governance on mineral rents by considering the corruption in mining sectors (e.g., Knutsen et al., 2017).

Control variables in this paper are trade volume and renewable energy consumption. We also control the country and time effects in all regressions. Trade is utilized by Ampofo et al. (2020) to examine the relationship between trade openness and natural rents for the top mineral-rich economies, and Awosusi et al. (2022) examined the impact of renewable energy consumption on environmental sustainability in their study.

3.2. Analytical modeling and estimation method

The regression model is characterized by the following equation (1),

\[ y_{it} = \beta_1 X_{it} + a_i + u_{it} \] (1)

where \( a_i (a = 1, \ldots, N) \) depicts the unknown intercept for every single parameter, \( y_{it} \) is the explained variable, where \( i \) denotes a country, \( t \) represents a period, \( X_{it} \) is the vector containing the explanatory variable. \( \beta_1 \) denotes the coefficient for the independent variable. Whereas \( u_{it} \) depicts the stochastic term. In model (2) below, we have added the time effect to the country effect model as given below.

\[ y_{it} = \beta_0 + \beta_1 X_{it} + \beta_2 C_{it} + \beta_3 T_{it} + u_{it} \] (2)

where \( \beta_2 \) depicts the coefficient for the binary regressors of the countries \( C_{it} \), and \( \beta_3 \) depicts the coefficient for the binary regressors of the period \( T_{it} \). Therefore, we control for the time effect due to variations, and events that might impact the mineral rents of the study countries.

The equation is re-parameterized as follows:

\[ MRTN_{it} = \beta_0 + \beta_1 GDP_{it} + \beta_2 CC_{it} + \beta_3 REC_{it} + \beta_4 Trade_{it} + u_{it} \] (3)

In the above equation (3), the \( \beta \) sign is used for coefficients with the name of variables, i.e., \( MRTN_{it} \) is mineral resources to total natural resources rent, \( GDP_{it} \) is GDP growth, \( CC_{it} \) is control of corruption, \( REC_{it} \) is the share of renewables energy in the aggregate final energy consumption, and \( Trade_{it} \) is a sum of exports and imports of goods and services measured as a share of gross domestic product.

We did several specification tests for error-component models using the Stata command xtest1. The results confirmed the random effects and our expectations concerning serial correlation. We adopted a random-effects GLS regression first and present the regression results. Afterwards, we show the results of the feasible generalized least squares (FGLS), panel-corrected standard errors (PCSEs), and Drißl-Kraay (DKSSEs) to address some potential econometrics problems like contemporaneous correlation considering the presence of data structure. These results are aimed at confirming the robustness of the results.

4. Results

4.1. Descriptive statistics

Table 3 summarizes the variables with their mean values and

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1 New Caledonia is a French unique collectivity in the southwestern Pacific Ocean, about 900 miles (1500 km) east of Australia. Despite being the primary supplier of cobalt and nickel, it is not included in the sample of this article since the key explaining variables are not included in the World Bank Development Indicator database.

2 The data and Stata code used in this study can be found at [https://osf.io/v7za2/?view_only=b86b11f43e6f2423b7749ca9029463a2f9].

3 We thank reviewer for the suggestion with respect to the robustness check.
Table 1: The top CM producing countries in 2020.

<table>
<thead>
<tr>
<th>Country</th>
<th>Cobalt</th>
<th>Copper</th>
<th>Lithium</th>
<th>Nickel</th>
</tr>
</thead>
<tbody>
<tr>
<td>DRC</td>
<td>39.4%</td>
<td>6.3%</td>
<td>6.3%</td>
<td>6.3%</td>
</tr>
<tr>
<td>Chile</td>
<td>27.8%</td>
<td>7.8%</td>
<td>7.8%</td>
<td>7.8%</td>
</tr>
<tr>
<td>Australia</td>
<td>54.2%</td>
<td>4.0%</td>
<td>4.0%</td>
<td>4.0%</td>
</tr>
<tr>
<td>Indonesia</td>
<td>39.4%</td>
<td>4.0%</td>
<td>4.0%</td>
<td>4.0%</td>
</tr>
<tr>
<td>Russia</td>
<td>8.9%</td>
<td>4.0%</td>
<td>4.0%</td>
<td>4.0%</td>
</tr>
<tr>
<td>New Caledonia</td>
<td>8.9%</td>
<td>4.0%</td>
<td>4.0%</td>
<td>4.0%</td>
</tr>
<tr>
<td>Canada</td>
<td>2.7%</td>
<td>4.0%</td>
<td>4.0%</td>
<td>4.0%</td>
</tr>
<tr>
<td>China</td>
<td>5.5%</td>
<td>4.0%</td>
<td>4.0%</td>
<td>4.0%</td>
</tr>
<tr>
<td>China</td>
<td>16.3%</td>
<td>4.0%</td>
<td>4.0%</td>
<td>4.0%</td>
</tr>
<tr>
<td>Russia</td>
<td>12.6%</td>
<td>4.0%</td>
<td>4.0%</td>
<td>4.0%</td>
</tr>
<tr>
<td>Russia</td>
<td>12.6%</td>
<td>4.0%</td>
<td>4.0%</td>
<td>4.0%</td>
</tr>
<tr>
<td>China</td>
<td>9.6%</td>
<td>4.0%</td>
<td>4.0%</td>
<td>4.0%</td>
</tr>
<tr>
<td>ROW</td>
<td>14.3%</td>
<td>4.0%</td>
<td>4.0%</td>
<td>4.0%</td>
</tr>
<tr>
<td>ROW</td>
<td>5.5%</td>
<td>4.0%</td>
<td>4.0%</td>
<td>4.0%</td>
</tr>
</tbody>
</table>

Note: ROW is the rest of the world. Source: Leruth et al. (2022).

4.2. Regression results and discussion

Table 5 presents the estimation for Random-effects GLS regression. Model 1 shows the results by including the variable CC with control variables. Model 2 uses the variable GDP with control variables. Model 3 adds all the variables. All variables in the models are controlled for country and year. The R-Squared and Wald chi2 tests show the fitness of the models. The positive and significant coefficients for GDP and Trade show a positive economic impact on mineral rents. This observation is in contrast with Sha (2022), who revealed that natural resources asymmetrically impact economic performance. Our results show that wealthier countries can develop and reap economic value from their critical minerals. The finding is in line with Leruth et al. (2022) and Weihed (2022). The value and statistical significance for the variable Trade show the importance of exports and imports of goods and services in improving mineral rents. It is documented that China has progressively moved from exporting its raw critical minerals to processing a more significant percentage of CMs while currently controlling more than 80% of the global processing of critical minerals. The significance demonstrates that these critical minerals are essential to economic development. These countries under investigation range from high economic values to mineral economic and lower economic values, depending on the criticality of the CMs, considering their supply restriction impacts and use. This result seems to confirm Ampofo et al. (2020) who argued that unravelled resource rents do not necessarily cause economic growth in many economies. Most critical minerals have very high economic value and are highly strategic and critical for national, economic, and infrastructural purposes.

The positive and significant coefficients for CC show that there is a positive regulatory impact on mineral rents. These results are meaningful as they denote the relevance of best mining practices, such as transparency and the rule of law in these countries, to achieve economic value and sustain the environment. The Policy Perception Index (PPI) discovered that some of these top mining countries have rather neglected factors like regulation quality, taxation levels or the quality of infrastructure as an indicator for the attractiveness of the investment.

The coefficients for REC are positive and statistically significant, and the value is very high compared to other variables’ coefficients. The significance shows the importance of REC in developing critical minerals that are essential for the energy transition. It implies that critical minerals are vital for the deep decarbonization of the economy, as these minerals are utilized to manufacture emerging technologies such as wind energy turbines, solar PV and parts for these technologies (Pommeret et al., 2022). Countries require minerals to manufacture solar panels with demand increasing to about 300% by the mid of the century, as well as minerals required for energy storage will increase by 1200% during this period. This result also confirms the outcome of a recent study that showed that REC facilitates economic development (Deng et al., 2022).

These findings shed light on the fact that regulation is central to developing these critical minerals, which are vital for the energy transition and to derive maximum economic value. The results are observed...
among the developing countries where mineral resources are responsible for a significant share of GDPs, as they might derive very little economic and environmental gains from these resources, but experience deteriorating socioeconomic and environmental impact instead. The Democratic Republic of Congo, for example, has experienced social unrest and slow economic development despite having abundant cobalt and copper reserves. However, countries such as Australia, China, and Canada, have progressively developed their economies with mineral rents based on a good regulatory performance (CC). These results have been discussed in greater detail elsewhere (Ampofo et al., 2020).

The findings of our study provide support to the paper by Janikowska and Kulczycka (2021) which postulated that a workable, sustainable mineral policy framework will lead to increases in the production capacity by 20%, as well as allow for reduced carbon dioxide emissions by 20% in Finland. According to Wind Power International (2021), the proportion of wind turbine installations based on direct drive turbines increased from about 18.2% in 2006 to 19.8% in 2011 and is expected to grow to 29.6% in 2020. As shown by Janikowska and Kulczycka (2021) there is a direct relationship between GDP and mineral resources (MR), as MR grows as a percentage of GDP, the GDP growth rate also increases. Australia, China, and Finland are countries that have exploited their critical minerals to accelerate the pace of economic growth (Janikowska and Kulczycka, 2021). In recent years, China has moved up the supply chains of critical minerals from exporting raw materials to exporting finished products during the 1990s and 2000s, which saw the GDP of China, grow exponentially to become the second-largest economy in the world while controlling about 80% of the processing of these critical minerals. All the variables are significant, implying the significance of these variables to the critical mineral development in these top CMs supplying countries.

### 4.3. Robustness check

Table 6 shows the robustness analysis of the panel variables. The test begins with the feasible generalized least square (model FGLS). The

<table>
<thead>
<tr>
<th>Table 2</th>
</tr>
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<tbody>
<tr>
<td><strong>Variables, abbreviations and their definition.</strong></td>
</tr>
<tr>
<td>Variable</td>
</tr>
<tr>
<td>Mineral Rents to Total Natural Resources Rents (MRTN)</td>
</tr>
<tr>
<td>GDP growth (GDP)</td>
</tr>
<tr>
<td>Control of Corruption (CC)</td>
</tr>
<tr>
<td>Trade (Trade)</td>
</tr>
<tr>
<td>Renewable Energy Consumption (REC)</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Descriptive statistics.</strong></td>
</tr>
<tr>
<td>Variable</td>
</tr>
<tr>
<td>MRTN</td>
</tr>
<tr>
<td>CC</td>
</tr>
<tr>
<td>Trade</td>
</tr>
<tr>
<td>GDP</td>
</tr>
<tr>
<td>REC</td>
</tr>
</tbody>
</table>

### 4.3. Robustness check

Table 6 shows the robustness analysis of the panel variables. The test begins with the feasible generalized least square (model FGLS). The

<table>
<thead>
<tr>
<th>Table 4</th>
</tr>
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<tbody>
<tr>
<td><strong>Correlations matrix.</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>MRTN</td>
</tr>
<tr>
<td>GDP</td>
</tr>
<tr>
<td>CC</td>
</tr>
<tr>
<td>Trade</td>
</tr>
<tr>
<td>REC</td>
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<table>
<thead>
<tr>
<th>Table 5</th>
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<tbody>
<tr>
<td><strong>Regression results.</strong></td>
</tr>
<tr>
<td>Variable</td>
</tr>
<tr>
<td>GDP</td>
</tr>
<tr>
<td>CC</td>
</tr>
<tr>
<td>Trade</td>
</tr>
<tr>
<td>REC</td>
</tr>
<tr>
<td>_cons</td>
</tr>
<tr>
<td>Wld ch2</td>
</tr>
<tr>
<td>R-squared</td>
</tr>
<tr>
<td>N</td>
</tr>
</tbody>
</table>

Note: *, ** and *** denote 10%, 5% and 1% significance levels respectively. Standard errors in parentheses; Variables related to country and year are controlled in all models.

### 4.3. Robustness check

Table 6 shows the robustness analysis of the panel variables. The test begins with the feasible generalized least square (model FGLS). The
second model calculates the panel-corrected standard error (PCSE) estimates for linear cross-sectional time-series models where the parameters are estimated by either OLS or Prais-Winsten regression, and Model 3 is based on the estimation using Driscoll-Kraay standard errors. From the results, all the variables have similar signs in Table 5, and all coefficients are statistically significant except Trade in the PCSE model. The results show the robustness of the regression results in Table 5.

5. Conclusions and policy implications

This study has explored the role of economic growth and governance on mineral rents in main critical minerals countries using data from World Bank development indicators and World Bank governance indicators between 2002 and 2019. The results demonstrate that the growth of mineral rent is directly impacted by economic growth, which implies that it promotes inclusive and equitable growth when appropriate expansive economic policies are implemented. High-developed countries have better been able to use mineral rents for economic progress, whereas lagging developing countries have been less successful. Similarly, the results show that mechanisms of good governance should be in place to avoid the abuse of mineral rents and to control corruption. This allows using critical minerals effectively for social and economic development. These fundamental issues are very prevalent in some developing nations where there is a race to the bottom in terms of environmental performance and pervasive corruption concerning the use of mineral rents, which might lead to further environmental destruction and greater dependency. By contrast, developed nations like the USA, Canada, and Australia have stricter environmental regulations.

The results of our paper show that renewable energy development is important for natural resource-endowed countries in fostering their economic and environmental performance. It has been shown that the consumption of renewable energy enables the supply of critical minerals, which can be used as raw materials for solar PV and wind energy farms. Therefore, policies are necessary that provide incentives for the deployment of renewables, such as tax rebates or decreasing costs for permits. To ensure that scale effects can be achieved in the deployment of renewables, some countries have already implemented these policy instruments. The findings demonstrate that some countries that efficiently manage their mineral resources are middle-income to high-income countries. In contrast, developing countries, especially low-income countries, are inefficient in equitably managing their mineral rents. We were able to show that the Pareto principle holds under these circumstances. To manage the technologies with large emissions calls for these countries to stockpile essential minerals to meet the soaring demand and guarantee supply security.

It is recommended that these countries invest in research and development that enables cutting-edge research on data gathering on mineral deposits and dissemination of information for further development. This will allow these countries to diversify the supply of these minerals from being concentrated in one country to avoid supply risk. In addition, more funding for scientific research on evaluating the whole mineral life cycle is required. It is crucial for technological latecomers to strengthen the resilience of relevant industrial chains by converting critical minerals into strategic emerging industries. Mineral resource-rich nations are also urged to improve their governance capacity. One limitation of the study can be attributed to the limited availability of data on critical minerals, but that did not affect the results of the paper. Future work should consider expanding the study by focusing on more countries producing critical minerals. This study should also provide incentives to researchers to provide more analyses on situations where the production of mineral resources is affected by fluctuations.

Author statement

Junguo Shi, Conceptualization, data acquisition, Writing – original draft, Funding acquisition, Supervision, and taking the lead in this project.
Yang Liu, Software, Data curation, and Writing – original draft.
Bert M. Sadowski, Writing- Reviewing and Editing.
David Alemzero, Conceptualization, discussion, and Editing.
Shanshan Dou, Conceptualization, Methodology, Writing – original draft, review & editing.
Huaping Sun, discussion, Editing, Funding acquisition.
Sobia Naseem, Conceptualization, Writing-review 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

The data and Stata code used in this study can be found at [https://osf.io/v7ax2/?view_only=b8e11f43e624228b749a9002463df9]

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