# Resilience of the Global EV Market under Cobalt Supply Risk Shocks

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***Abstract***: Electric vehicles (EVs) are a key driver in the global low-carbon energy transition, with their market undergoing rapid expansion. Cobalt, a crucial raw material for EV battery production, sees most countries exhibiting high dependency on its import. Recent geopolitical conflicts have further amplified concerns regarding the global EV market's resilience in handling cobalt potential supply risk shocks.

In this study, we use the 11th edition of the GTAP database, combined with micro-level data on the cost composition and supply structure of cobalt mining enterprises, to disaggregate a dataset covering the trade flows of cobalt commodities. We then construct a global multi-regional computable general equilibrium (CGE) model that accounts for the unique characteristics of cobalt commodities to quantitatively analyze the impact of cobalt supply risks on the global EV market.

Our analysis focuses on assessing the EV market's resilience under various

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cobalt supply risk scenarios. Resilience is specifically defined as encompassing two capacities: resistance and recovery. Resistance capacity is measured by changes in production and import-export trade in the short term, while recovery capacity is gauged by the duration of production stabilization in the long term, as well as the time taken to develop alternative materials. We will analyze the research results from two perspectives: firstly, discussing from a global viewpoint how different levels of cobalt supply risks reshape the international trade structure of the EV market; secondly, examining the heterogeneity among countries in their resistance capacity and recovery capacity in the EV market under the conditions of cobalt supply risks.

The significance of this study lies in clarifying the impact of cobalt supply risks on the resilience of the EV market, providing crucial insights for policymakers tasked with navigating these challenges.

***Keywords*:** Cobalt, EV Market, Resilience, GTAP

***JEL Codes*:** C68; F14; F17



The structure of this study is as follows: The first section introduces the research context and reviews existing literature on cobalt price volatility and EV market resilience. The second section outlines our methodology and data sources, focusing on the disaggregation of the coblet commodity input-output table and the development of the CGE model. The third section presents scenario analysis, analyzing the EV market's response to various cobalt supply risk scenarios at both global and national levels. The final section draws conclusions and offers policy recommendations.

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# 1. Introduction

## 1.1 Background

Climate change is sounding an alarm for human society. Reducing greenhouse gas emissions, curbing global temperature rise, and achieving carbon neutrality are proactive and collective pursuits in facing the climate crisis. According to the United Nations, the transportation sector is the largest source of carbon emissions on the consumption side globally, dominated by vehicles and other transport tools powered by fossil fuels. EVs (EVs), as an effective alternative to fuel-powered vehicles for reducing greenhouse gas emissions, play a pivotal role in the global low-carbon energy transition.

In recent years, the EV market has experienced unprecedented growth. According to the International Energy Agency, EV sales are expected to continue to rise over the next decade, with EVs making up more than 35% of new car sales by 2030. The robust emergence of EVs has driven up demand for batteries and related key minerals. Cobalt, with its unique chemical properties, is one of the indispensable cathode materials for manufacturing EV batteries. The International Cobalt Association reports that global cobalt demand reached 187,000 tonnes in 2022, a 13% increase year-on-year, with the EV sector showing the most significant demand, consuming 74,000 tonnes of cobalt, surpassing traditional battery fields for the second consecutive year.

However, the global supply of cobalt faces significant risks, primarily due to the high concentration of cobalt mining, processing, and consumption (Wang and

Yuan, 2022). Over 70% of the world's cobalt commodities production is concentrated in the Democratic Republic of Congo (DRC), and more than 60% of cobalt refining is done in China, with over 95% of China's cobalt commodities imported from the DRC. This high dependence on a single country increases the vulnerability of the supply chain. Political instability, economic fluctuations, or policy changes within the DRC, as well as issues like child labor and labor rights violations in Congolese mines, could directly impact global cobalt supplies. Moreover, the intensifying geopolitical tensions over key mineral resources and rising resource nationalism that restricts mineral exports have led to tighter supplies and price volatility of critical minerals like cobalt, subsequently affecting the development of the EV industry.

The high demand for cobalt in the EV market, combined with uncertainties in cobalt supply, tests the market's ability to withstand shocks from cobalt supply risks. This study constructs a global multi-regional computable general equilibrium (CGE) model, incorporating the cobalt sector and cobalt supply disruption scenarios, to quantitatively analyze the impact of cobalt supply risks on the global EV market and reveal the market's resilience against cobalt supply risks. This provides crucial insights for promoting the sustainable development and supply chain stability of the EV industry.

## 1.2 Literature Review

As the rapid development of the new energy vehicle industry continues, cobalt's consumption potential and strategic position are increasingly highlighted.

Major consuming countries worldwide, including the EU, the US, Japan, and China, have included cobalt in their critical minerals list. With cobalt's rising strategic importance, nations have begun to seek effective methods to track the flow of this essential resource. Material flow analysis enables the quantification of the complete process from cobalt extraction to final use. Existing studies using this method have quantified the flow of cobalt resources in production, manufacturing, consumption, and recycling stages in countries such as China, the US, Japan, and the EU (Sun et al., 2019; Zeng et al., 2022). Zeng et al. (2022) used material flow simulation for historical data from 1998-2019 to forecast global cobalt circulation from 2020 to 2050, indicating that cobalt supply shortages are inevitable in the short to medium term between 2028 and 2033.

Material flow analysis focuses on the cobalt footprint within single economies, while studies on international trade risks often utilize complex network analysis methods (Zhao et al., 2020). Zhao and Chen (2024) constructed a trade network to reveal the spatial pattern and topological structure of the global cobalt trade network, discovering significant core-periphery structural characteristics, with countries like China, the UK, the US, and Germany consistently occupying central positions in the trade network, while the DRC exerts strong control over the overall operation of the cobalt product chain. Furthermore, Zhao et al. (2022) analyzed the dynamic impact of changes in the trade dependency network structure on the price fluctuations of products along the cobalt industry chain, finding that downstream lithium battery prices are most affected by changes in the trade network structure, followed by upstream cobalt mines, with midstream cobalt product prices least affected.

Although many studies emphasize the supply risks in the cobalt industry chain, research discussing the potential impacts of upstream cobalt mine supply risks remains limited. Computable General Equilibrium (CGE) models can simulate the effects of natural disasters, trade policies, and market changes on economies (Hertal et al., 2007). On one hand, existing research has used CGE models to explore the impact of supply chain risks across various sectors; Sun et al. (2024) simulated how future extreme heatwave risks could magnify economic costs through global supply chains, Tanaka T et al. (2021) modeled the impact of wheat export restrictions on global food supplies, and Cui et al. (2019) simulated the impact of US-China trade disruptions on various industries and changes in trade structures. On the other hand, some studies have incorporated mineral resources into the CGE model framework; Xu et al. (2020) investigated the impact of price fluctuations of rare earth elements on China's rare earth industry, finding that price volatility could lead to instability in industry investment and production; Zong et al. (2018) constructed a dynamic multi-regional CGE model to study the effects of China imposing a copper tax on the economy and resources; Amir H. (2013) used a CGE model to analyze the impact of Indonesia's mineral export restriction policies on its own economy.

In summary, current research has provided a solid theoretical basis for understanding mineral resource supply risks, and the flow and trade risks of cobalt resources are well supported by empirical evidence. However, the potential impacts of upstream cobalt mine supply risks require further exploration, and using CGE models to quantify the effects under different risk scenarios could fill this research gap in the field.

# 2. Methodology and Data

## 2.1 Model Construction

The Computable General Equilibrium (CGE) model is a mathematical model used to assess the impact of economic policy changes on the interdependencies among various sectors of an economy. This paper utilizes the Global Trade Analysis Project (GTAP) model developed by Purdue University (Hertel, 1997; Corong et al., 2017), which is a multi-regional CGE model. Due to its ability to simulate the impacts of changes in international trade, it is widely used in studies concerning tariff policies, trade agreements, and other issues. To investigate the effects of cobalt supply risks on the EV market, this study first adjusts and merges the national sectors in the GTAP 11 database to retain 12 main economies involved in cobalt production, use, and consumption—China, the United States, Japan, South Korea, Germany, the United Kingdom, Finland, Australia, Russia, the Democratic Republic of the Congo, and other countries—and 15 related sectors, as shown in Table 1.



Table 1. Sector Division and Description

| New sector | Old sector | Description |
|---|---|---|
| agr | pdr wht gro v fosd c b pfb ocr ctl oap rmk wol frs fsh | Agriculture,forestry,animal,husbandry and fisheries. |

| | | |
|---|---|---|
| fop | cmt omt vol mil pcr sgr ofd b t tex wap lea lum ppp | Processed food and textiles, etc. |
| cog | coa oil gas p_c | Energy sector, etc. |
| oxt | oxt | Minerals, etc.(Cobalt Concentrate will be split from this sector) |
| nmm | nmm | Mineral products, etc. |
| nfm | nfm | Metals, etc. (Refined Cobalt will be split from this sector) |
| fmp | fmp | Mental products. |
| chm | chm | Chemical products. |
| eeq | eeq | Electrical equipment. |
| mvh | mvh | Motor vehicles and parts.(EVs will be split from this sector) |
| otm | bph rpp i s ele ome otn omf | Other manufactures, etc. |
| egw | ely gdt wtr | Electricity and gas and water manufacture, etc. |
| stp | otp wtp atp | Transport, etc. |
| whs | whs | Warehousing and support activity. |
| ots | cns trd afs cmn ofi ins rsa obs ros osg edu hht dwe | Other services, etc. |



## 2.2 Splitting the GTAP Database

To explore the study's theme further, it is necessary to segment the cobalt commodities, refined cobalt, and EV sectors. Initially, the non-competitive input-output tables from the GTAP 11 database for each country are split. Subsequently, the sectoral values are inputted into the database using Splitcom, completing the segmentation of the GTAP database.

### 2.2.1 Input-Output Table Segmentation

The mining sector (oxt) is divided into Cobalt Concentrate and other minin, and the metals sector (nfm) is split into refined cobalt and other metals.

① Production data: This study mainly relies on production data for Cobalt

Concentrate and refined cobalt provided by the U.S. Geological Survey (USGS), along with cobalt price data also published by the USGS.

② Trade data: Trade flow information is primarily sourced from UN Comtrade, including Cobalt Concentrate (HS: 260500) and refined cobalt (HS: 8105, 282200, 282739, 291590), where the HS codes for cobalt chloride and cobalt acetate require precision to six digits or more, with variations existing across countries; trade flows for cobalt acetate and cobalt chloride are obtained from the Trademap database.

Using production and trade data, balance sheets for Cobalt Concentrate and refined cobalt are compiled for each country to obtain comprehensive usage data.

③ Intermediate inputs and usage data: Material flow analysis is one of the most effective methods to track the pathways of material flows, which primarily consist of stages such as extraction, smelting, product processing, manufacturing, usage, and waste management. Existing studies have analyzed cobalt material flows in various regions, including globally, China, the United States, the European Union, and Japan. This research collects and integrates intermediate usage ratios of cobalt from publicly available cobalt material flow literature (assuming domestic and imported goods ratios are consistent), where the stage from Cobalt Concentrate to refined cobalt corresponds to the smelting phase, and the usage of refined cobalt corresponds to the product processing and manufacturing phase. For countries where specific usage ratios are not found, the global cobalt material flow ratios published by the International Cobalt Association are used.

④ Inventory changes: Data regarding inventory changes are sourced from The New York Stock Exchange.

⑤ Others: Due to the specific attributes of the mining and metals sectors, the final usage ratios for Cobalt Concentrate and refined cobalt are aligned with those sectors, and the value-added parts are also supplemented using proportional methods.

The motor vehicles and parts sector (mvh) is divided into EVs and other vehicles. Trade data are sourced from UN Comtrade. For production and usage, this study primarily divides the mvh sector based on the market shares of EVs and fuel vehicles in each country, adjusting the input-output ratios of the related sectors based on the differences in batteries and engines between electric and fuel vehicles.

**2.2.2 Splitting the GTAP Database**

The GTAP model not only involves data from input-output tables but also encompasses broader macroeconomic data, tariffs, consumer preferences, etc. Therefore, when a detailed analysis of the split industries is required using the GTAP model, the entire database must be segmented and adjusted. Splitcom is a tool for dividing sectors within the GTAP database that can maintain overall database balance while performing sector splits and structural adjustments based on user settings through a linear interpolation method. This research inputs the data from the split input-output tables into Splitcom to generate a GTAP database that includes sectors for cobalt concentrate, refined cobalt, and EVs.

## 3. Simulation Scenario

Due to frequent political instability, armed conflicts, and lack of effective governance in the Democratic Republic of Congo (DRC), coupled with social issues such as child labor and illegal mining in cobalt extraction, significant risks to the supply of cobalt are introduced. These risks could prompt government actions to restrict or prohibit the export of cobalt from the DRC. Two scenarios are designed as follows:

Scenario 1: Due to labor issues, political instability, or natural disasters, cobalt exports from the DRC are reduced by 50%.

Scenario 2: In the event of an extreme situation, such as a full-scale civil war in the DRC or an international trade embargo, cobalt supply is completely interrupted, resulting in a 100% reduction in exports.

In recent years, with the rise of global trade protectionism and resource nationalism, the global cobalt supply chain faces dual challenges. Over the past 15 years, export restrictions on critical minerals by countries around the world have increased fivefold, assuming the cost of free movement of cobalt in the global trade network increases, and producing countries raise tariffs on cobalt exports. Two additional scenarios are designed as follows:

Scenario 3: With the rise of global resource nationalism, cobalt-producing countries increase tariffs on cobalt to protect their domestic resources by 30%.

Scenario 4: Amidst global trade tensions and protectionist sentiments, cobalt-producing countries impose higher export tariffs on cobalt, increasing them by 60%.

Table 2. Cobalt Supply Risk Scenario Settings

| Scenario | Description |
| --- | --- |
| Scenario 1 | Cobalt exports from the DRC decrease by 50% |
| Scenario 2 | Cobalt exports from the DRC decrease by 100% |
| Scenario 3 | Cobalt export tariffs increase by 30%. |
| Scenario 4 | Cobalt export tariffs increase by 60% |



# 4. Results

## 4.1 Resistance capacity

(1) Impact on the Macro Economy

(2) Impact on EV Production

(3) Impact on EV Market Prices

(4) Impact on EV Trade

Analysis of Scenario 2 Results:

Price Levels: Assuming that, apart from the DRC, the production of cobalt concentrate in other countries remains consistent with current levels, a reduction in DRC exports will lead to a global cobalt supply shortage. Coupled with sustained high demand, this will drive up the price of cobalt concentrate by 137.74%. Due to the increase in raw material prices, the price of refined cobalt will also increase by 143.75%. Given the critical role of refined cobalt in the production of EV batteries, the price of EVs will be pushed up by 1.51%. The export price of EVs from China will see a larger increase, approximately 3.21%, while the export prices in the USA and Germany will rise by 1.25% and 0.67%, respectively.

Production Levels: China is the largest producer of refined cobalt globally, with approximately 99% of its cobalt commodities imported from the DRC. Therefore, when exports of cobalt commodities from the DRC are interrupted, China will increase imports from other countries, but these alternative sources cannot replace the significant share of DRC cobalt commodities. This will still lead to a reduction in China's refined cobalt production by about 28.4%, further causing a decrease in new energy vehicle output by 4.03%. Due to the rise in refined cobalt prices, the production of refined cobalt in the USA, Japan, Canada, and other countries will slightly increase, to some extent compensating for the lack of supply from China. Additionally, the supply of refined cobalt required for producing EVs in the USA not only comes from domestic production but also from imports from China, Japan, Canada, and other countries. Hence, its supply of refined cobalt is less affected, enhancing its competitiveness in the international market and leading to an output increase of 0.61%. Similarly, Germany's supply of refined cobalt is relatively diversified, which minimizes the impact of the DRC export interruption, resulting in a 4.12% increase in EV output.

Trade Patterns: Following the reduction in cobalt commodities exports from the DRC, the export shares of cobalt commodities from most countries rise, with Russia's exports increasing by 101.14%. Other countries become the largest global suppliers of cobalt commodities, with the share supplied to China increasing by 46.83%, becoming a significant source of cobalt commodities imports for China, while exports to other countries decline. China's position as the world's largest exporter of refined cobalt will be overtaken, with significant reductions in exports being replaced by Finland, Canada, and other countries. Simultaneously, China's imports of refined cobalt from Finland and Canada increase by 148.31% and 139.53%, respectively. Although imports of cobalt commodities and refined cobalt from countries like Finland partially compensate for the cobalt supply shortage in China, its EV market still suffers significant impacts. Exports of EVs from China decline overall, especially to the European market, with exports to Germany and the UK falling by 8.74% and 10.16% respectively. This could be due to Chinese EVs losing competitiveness in the international market because of the larger increase in export prices, while the US and Germany, with smaller increases in export prices, see their EV exports rise by 2.04% and 4.9%, respectively.

The results and analysis for the other scenarios are pending integration.

## 4.2 Recovery capacity

The completion of this section remains pending as we contemplate the dynamization of the model to better capture the evolving nature of the global cobalt supply chain and its economic impacts.

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