A Framework Detecting Risk of Geopolitical Competitions over Critical Minerals and a Case Study of Copper

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***Abstract*—Geopolitical competitions over critical minerals are threaten the stable supply of critical minerals for renewables sector. The study builds a risk detecting framework for risks of geopolitical competitions over critical minerals and takes copper as a case study. The framework includes risk source, risk formation and risk transmission, three components. Risk source captures the objective chances, risk formation identifies risk forming potential from intention and obstacle perspective, risk transmission measures the magnitude of risk impacts. Risk of geopolitical competitions over copper is analyzed as a case study. The results show that in average, risk of geopolitical competition over copper is within the range of threshold risk level. The highest risk comes from geo-core importers, the lowest comes from geo-core exporters. The highest risk for copper could from Chile, Peru, Kazakhstan, Indonesia, D.R. Congo, China EU, USA, Australia, and Canada. The framework developed in this paper can be applied to other critical minerals as well and can be used to deliver comparable results.**

***Keywords*—risk detecting, analyzing framework, geopolitical competition, critical mineral, copper**

I. Introduction

Critical minerals specifically refer to minerals important to high-tech, national defense, and national important industries. In this paper, we focus on critical minerals that are important raw materials of the renewable energy industry. IEA Critical Minerals Data Explorer predicted that demand for critical minerals will increase greatly, for the stated policies scenario, copper demand will increase from 26.6 to 37.4 metric million tons from 2024 to 2050. While supply of critical minerals are suffered from various risks. EY reported top 10 risks for mining and metals companies in 2025, geopolitics is listed in the third-place following capital and environmental stewardship.

The study built a risk detecting framework to detect the risks of geopolitical competitions over critical minerals. The framework identifies the risk source, risk formation and risk transmission. Wherein, risk source captures the objective chances, risk formation indicates forming potential from intention and obstacles perspective, risk transmission measures the magnitude of risk impacts. Risk level of copper in 2023 is taken as an example.

The following article is organized as bellow. Following this introduction is a method section embodying risk detecting logic, and aggregating method. The third section gives a case study of copper with data source, and results. The fourth section concludes the paper.

II. Literature Review

Geopolitical competitions over critical minerals are threaten the stable supply of critical minerals. Månberger & Johansson (2019) studied 14 metals and metalloids needed in renewable energy technologies, and structured five processes that energy and materials interact with geopolitics. They are mineral supply security for importers, resource rent appeals for exporters, trade flow safeties, political influence of resource sovereign side, and resource governance to avoid resource curse. Kalantzakos (2020) described the geopolitical race for critical minerals, wherein, he addressed the cognition that securing access to critical minerals will both impact and help shape future geopolitics. Dou *et al.* (2023) mentioned that increased competition of critical minerals let their supplies change from economic priority to security priority, and countries has replaced relevant regulations to protective ones. Vivoda *et al.* (2024) investigated the competition of the control over minerals supply chain between western-based trading system and BRICS+6 nations, and pointed out its impact on the trading order and mineral market stability. Huda (2024) constructed a conceptual framework on renewable energy diplomacy, wherein he proposed collaborative resource governance countering using critical minerals as a geopolitical tool to control productions.

III. Materials and Methods

A. Risk Detecting Logic

To detecting the risk of geopolitical competition over critical minerals, the first question to answer is “from whom”. The “whom” indicates the Risk Source (RS). In the study, country level risk subjects are considered. According to the knowledge of geopolitics studies, not all countries have equally geopolitical impacts [6]. Based on a country’s geographical position and economics status, the paper divides countries into geopolitical core (geo-core) region and geopolitical peripheral (geo-peripheral) region, Table 1. And based on a country’s position in copper mineral supply, the paper divides countries into exporters and importers. Total four risk subjects are captured by above dual classifications: geo-core importers, geo-core exporters, geo-peripheral exporters, and geo-peripheral importers. Since the paper consider copper as from critical mineral aspect not the base metal aspect, geo-peripheral importer is eliminated.

Table 1. Classifications of geopolitical status of countries

State Power Level by Cohen (2019)		State Economic Status by World Bank	Geopolitical Classification by the Authors
1st level	USA EU Japan Russia China	Regardless of economic status	Geo-core region
1st level (potential)	India		
2nd level	Brazil	2000–2018: above Upper Middle Income (UMI) 2019–2022: below UMI	2000–2018: core 2019–2022: peripheral
	Canada	Above UMI	Core
	Turkey	2000–2020: above UMI 2021–2022: below UMI	2000–2020: core 2021–2022: peripheral
	Australia	Above UMI	Core
	Iran	2000, 2002–2013: above UMI 2001, 2014–2022: below UMI	2000, 2002–2013: core 2001, 2014–2022: peripheral
	South Africa	2000–2012: above UMI 2013–2022: below UMI	2000–2012: core 2013–2022: peripheral
	Nigeria	Below UMI	Peripheral
	Indonesia	Below UMI	Peripheral
	Rep. of Korea	Above UMI	Core
	Vietnam	Below UMI	Peripheral
	Israel	Above UMI	Core
	Mexico	Above UMI	Core
	Pakistan	Below UMI	peripheral
	Egypt	Below UMI	peripheral
	Venezuela	2000–2015: above UMI 2016–2022: below UMI	2000–2015: core 2016–2022: peripheral
	Saudi Arabia	Above UMI	Core
	Algeria	2000–2003, 2008–2022: below UMI 2004–2007: above UMI	2000–2003, 2008–2022: peripheral 2004–2007: core
	Thailand	2000–2005: above UMI 2006–2022: below UMI	2000–2005: core 2006–2022: peripheral
	Argentina	2000–2020, 2022: above UMI 2021: below UMI	2000–2020, 2022: core 2021: peripheral
Other countries		Regardless of economic status	Peripheral

To capture the risk level of each Risk Source (RS), contribution of a country's market share in total Herfindahl-Hirschman Index (HHI) is used, Eq. (1). Because HHI indicates market concentration ratio, which reflects the potential existence of market power. In a competitive market, market participants get less chances to obtain monopoly profits and lead to market failures. As the competitiveness goes down, more chances for monopolistic behaviors appear. For geo-peripheral exporters, it means higher chances to implement higher tax levels so as to obtain more rents. For geo-core importers, it means higher chances to control mineral supplies to avoid being threatened by supply interruptions. For geo-core exporters, it means higher chances to split domestic and international markets, in order to benefit domestic downstream industries. In Eq. (1), means share of supply or demand in the total.

$$RS = \frac{{S_i}^2}{\Sigma({S_i}^2)} \tag{1}$$

After detecting the RS, the second question to answer is "why and how", means the Risk Formation (RF). For geo-peripheral copper exporters, they peruse mineral rents to support domestic economy [7]. The higher dependency on mineral rents, the stronger the intention to grab mineral rents. But if the mineral tax level is already very high, it means the remaining space to increase mineral rents is low. And the resource quality also plays an important role. If a country's average mining cost is relatively high compared to other suppliers, the economic allowable increase of its mineral rent is limited. Therefore, the RF of geo-peripheral exporters can be expressed as Eq. (2), as seen, it is directly proportional to mineral dependency, and inversely proportional to mineral tax burden and mining production cost level.

$$RF_{geo-peripheral\ exporter} = \frac{mineral\ rent\ dependecy}{mining\ tax\ burden} \times \frac{1}{mining\ cost\ level} \tag{2}$$

For geo-core copper importers, they are worried of the security of critical mineral supplies. Critical minerals are indispensable raw materials for their clean energy technologies, and occupy a significant share in the final product cost. So, they hold high intention to control the upstream mineral supply. As their self-mineral dependency increases, and their opponent mineral dependency decreases, their intention to involve into upstream mineral supply grows stronger. The achieve of the mineral control gives them opportunities to control mineral supplies to a favored one to themselves, like using price discriminations or supply interventions. This opportunity is neutralized by downstream production position, because such supply control behaviors also impair their own downstream industries. Therefore, the RF of geo-core importers are expressed as below, Eq. (3).

$$RF_{geo-core\ importer} = \frac{self\ import\ dependency}{sopponent\ import\ dependency} \times \frac{1}{downstream\ production\ share} \tag{3}$$

For geo-core copper exporters, they have high intention to be involved in downstream high-tech industries to transform development momentum towards technology orientated ones, and further to achieve more sustainable developments. The higher share in raw mineral supply and lower share in downstream products' supply, the higher intention of them to enter downstream high value-added supply chain. But if they rely heavily on mineral revenues, the acting space for them to differentiate domestic and international markets are small. Therefore, the RF of geo-core exporters are expressed as below, Eq. (4).

$$RF_{geo-core\ exporter} = \frac{share\ in\ mineral\ supply}{share\ in\ downstream\ product\ supply} \Big/ \frac{1}{dependency\ on\ mineral\ rents} \quad (4)$$

The last question to answer is "the impacts", means the Risk Transmission (RT). There are twofold, the specific type of impacts and the magnitude of them. For geo-peripheral exporters, an increase of mineral rents can lead to supply interruptions. Because mining companies have to re-evaluate the project feasibility or to contradict the new contract given. The magnitude of the risk to mineral supply depends on the production share of the country occupies. Therefore, RT of geo-peripheral exporters can be expressed by the share of production, Eq. (5).

$$RT_{geo-peripheral\ exporter} = \frac{mining\ production\ of\ a\ country}{world\ mining\ production} \quad (5)$$

For geo-core importers, a trial to control the upstream mineral supply sector means investment in mining domestically. Since geologically minerals are unevenly distributed in the earth, the potential to invest in mining productions are limited by the resources actually buried in place. The specific impact of supply control behaviors is market volatility. Because supply market could become monopolized or fragmented, with mounted opportunistic behaviors and political monitors. The magnitude of the impact depends the investment potential of a specific country. Therefore, RT of geo-core importers can be expressed by the share of reserves a country hold, Eq. (6).

$$RT_{geo-core\ importer} = \frac{reserve\ size\ of\ a\ country}{world\ reserve\ size} \quad (6)$$

For geo-core exporters, a penetration into downstream high-tech sector means using the mineral sector to benefit the downstream industries, by downstream tax credits and export limitations. These measures will split mineral supply market into domestic low-price paradise and international high-cost hells. It forces international downstream mineral demanders invest into upstream minerals for self needs as well as create less mineral intensive technologies and crafts. And finally lead to over investment of upstream minerals. The impact magnitude that a market fragmentation brings out depends on the share of production a country occupies. Therefore, RT of geo-core exporters can be expressed by the share of production a country contributes, Eq. (7).

$$RT_{geo-core\ exporter} = \frac{mining\ production\ of\ a\ country}{world\ mining\ production} \quad (7)$$

B. Aggregating Method

According to the risk detecting logic, the risk of geopolitical competition over copper is defined as the logarithmic value of the product of risk source, risk formation and risk transmission, Eq. (8). The range method is used to standardize all indicators. In the Eq. (9), represents the original value of an indicator, represents the original range of an indicator, subscript max means the minimum value and the subscript min means the maximum value, represents the standardized values. Three sub-indicators RS, RF, and RT are standardized into [1,10000]. And the RISK thus belongs to [0,12], and further standardized to [0,5] using the range method.

$$RISK = Log_{10}(RS \times RF \times RT) \quad (8)$$

$$F_i = \frac{L_i - L_{min}}{L_{max} - L_{min}} \times (F_{max} - F_{min}) + F_{min} \quad (9)$$

IV. Result and Discussion

A. Data Source

Data of the study are obtained from official database and reports, commercial reports of companies and associations (Table 2). For copper mining tax burden of a country, a simple addition of Cooperate Income Tax (CIT) and mineral taxes is used. Because countries have very much varied taxation systems, it is difficult to accurately capture each countries tax burden. What's more, within a country, tax burdens may vary according to operating capacities, specific policies, profitability of mining projects, as well as ownership structures, etc. Pwc Mining Tax Summary Tool is used to extract the tax information, but for those countries not embodied in the tool, we checked individually about its CIT and minerals taxes. Mining visuals published a picture of mining cost levels of dominant copper mining companies; their data is used to compute average mining cost of each country without considering specific projects' outputs. For mining investment potential of a country, if there is information published by USGS, it is adopted; for those not published, computations by authors through national geological survey and companies' reserve information are used. For downstream industrial related information, photovoltaic sector is considered. Because in renewable energy sector, PV consumes most of copper, so far, as reported by IEA Critical Minerals Data Explorer. For RS and RT indicators, absolute values are applied to aggregation. For RF indicators, relative values are applied. It means that we use range standardization method to process the raw data. Because in a game set, what matters is comparing strength.

B. Risk Detecting Results

The results show that in average the risk from geo-peripheral copper ore and concentrate exporters for mineral rents falls into the threshold risk level (Fig. 1). Chile holds the highest risk potential, which is dominated by its risk sourcing and transforming ratio. Peru, Kazakhstan, Indonesia, and Dem. Rep. of the Congo fall into threshold risk level, which should be alerted. The risk compositions of them are dominated by risk sourcing and transforming as well, with Kazakhstan and Dem. Rep. of the Congo have relatively larger portions generated from the risk forming stage.

Table 2. Indicators and data sources to detecting the risk of geopolitical competitions of copper

Risk Subjects	Risk Constructions	Risk Indicators	Data Source
Geo-peripheral exporter	Risk Source (RS)	HHI contribution of a country to the total HHI of copper exports	UN.ComTrade database Series: HS2603, export
	Risk Formation (RF)	Mineral rent dependency of a country	World Bank Data Series: mineral rent (%GDP)
		Copper mining tax burden of a country	Pwc Mining Tax Summary Tool; Web information
		Copper mining cost level of a country	MiningVisuals
	Risk Transmission (RT)	A country's share in total copper mining supply	World Mining data
Geo-core importer	Risk Source (RS)	HHI contribution of a country to the total HHI of copper imports	UN.ComTrade database Series: HS74, import
	Risk Formation (RF)	Copper import dependency of a country	World Mining data; UN.ComTrade database Series: HS2603, import
		Copper import dependency of a competitor	World Mining data; UN.ComTrade database Series: HS2603, import
		Downstream industrial supply position of a country	IEA PVPS country report
	Risk Transmission (RT)	Mining investment potential of a country	USGS; Web information
Geo-core exporter	Risk Source (RS)	HHI contribution of a country to the total HHI of copper exports	UN.ComTrade database Series: HS2603, export
	Risk Formation (RF)	Share in copper mineral exports	UN.ComTrade database Series: HS2603, export
		Share in downstream product exports	UN.ComTrade database Series: HS 850171, 850172, export
		Mineral rent dependency of a country	World Bank Data Series: mineral rent (%GDP)
	Risk Transmission (RT)	A country's share in total copper mining supply	World Mining data

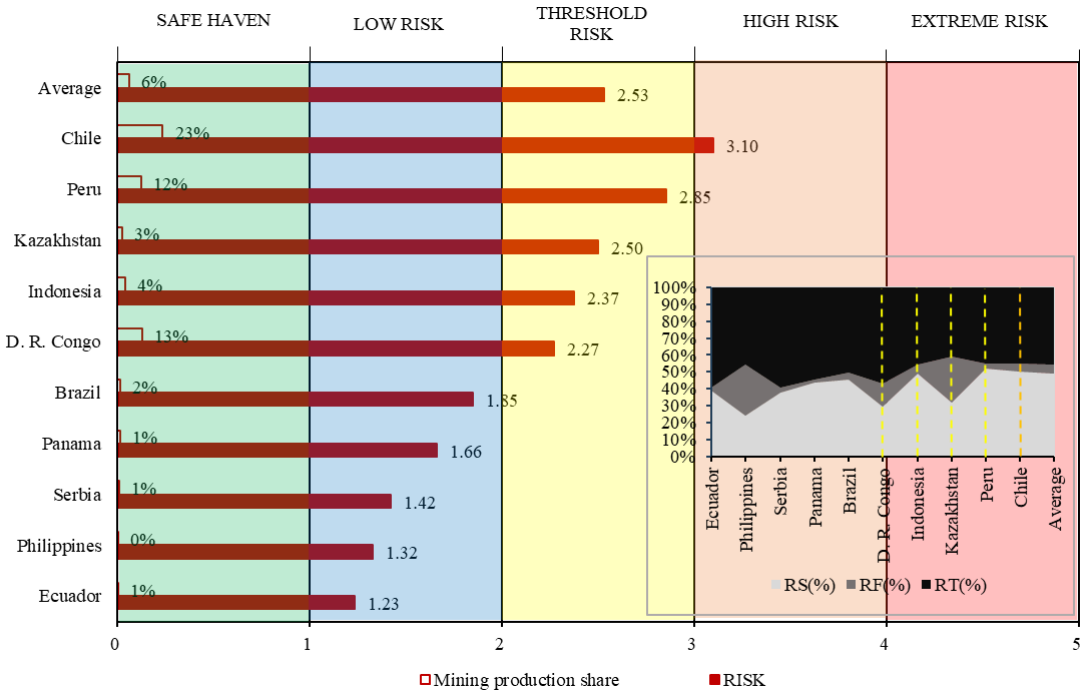

Fig. 1. Risk level and composition of geopolitical competitions over copper rents from geo-peripheral exporting regions.

The results show that in average the risk from geo-core copper and articles thereof importers for mineral supply control falls into the threshold risk level (Fig. 2). China and EU as a whole hold the highest risk potential, which belong to the high-risk interval. Other two countries crossing the interface of low risk and threshold risk are USA and India. Compared to the risk generated geo-peripheral exporters, risk forming potential of geo-core exporters are higher. It is caused by a fact that downstream manufactural capacities are extremely unevenly distributed, with most of the them located in China.

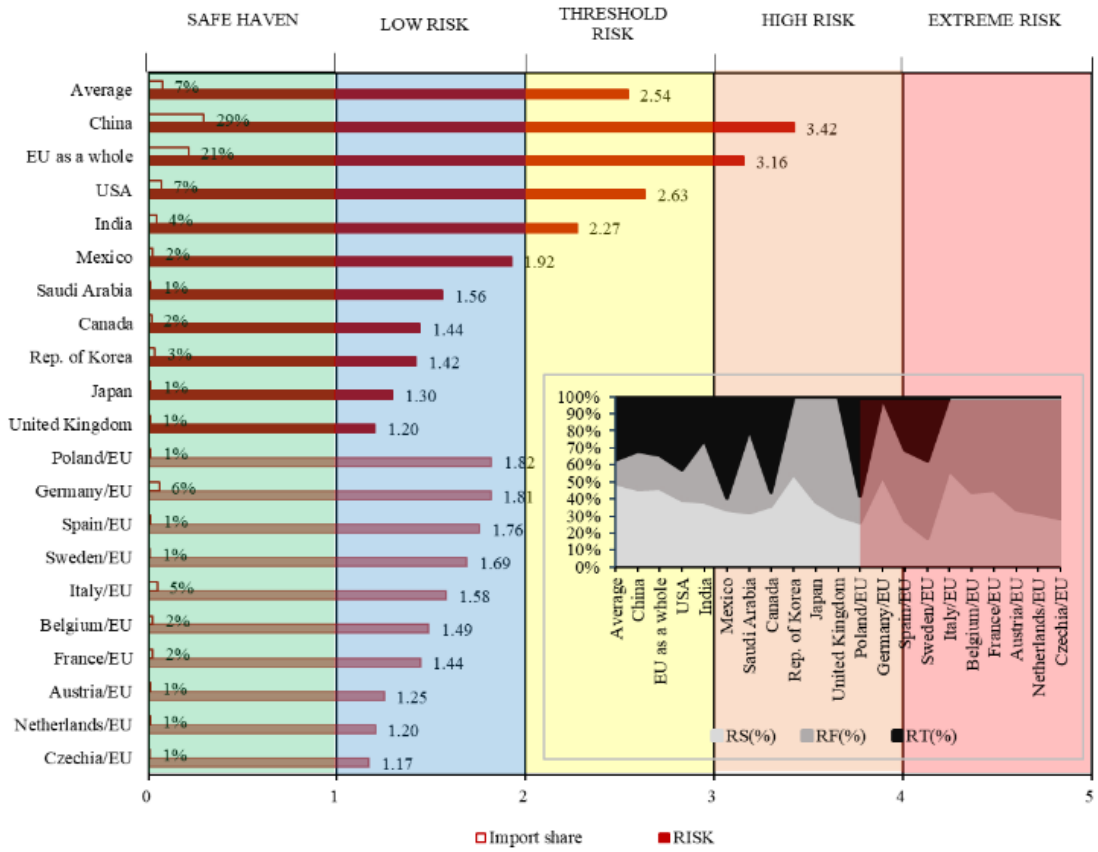

Fig. 2. Risk level and composition of geopolitical competitions over copper supply controlling forces from geo-core importing regions.

The results show that in average the risk from geo-core copper ore and concentrate exporters for downstream manufactural dominance falls into the low-risk level, but near the lower threshold of the threshold risk interval (Fig. 3). Three countries, Australia, Canada and USA show higher risks, fall into the threshold risk interval. For Australia, risk source, formation and transmission share the risk composition almost evenly. For Canada and USA, risk source and transmission dominate. It is led by their minor position in both mineral exports and downstream products exports.

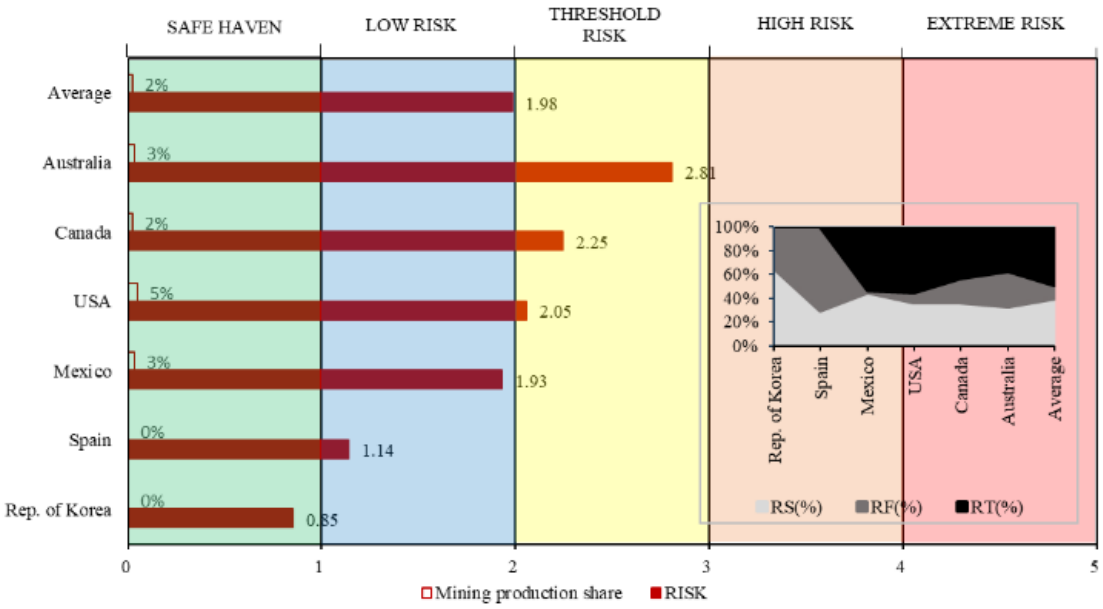

Fig. 3. Risk level and composition of geopolitical competitions over copper downstream industrial dominance from geo-core exporting regions.

Aggregating all three aspects of risks together, a risk feature of geopolitical competitions over copper can be obtained (Fig. 4). In average, risk of geopolitical competition over copper is within the range of threshold risk level. The highest risk comes from geo-core importers, the lowest comes from geo-core exporters. It means that the copper demanders, mainly China and the EU penetrating the copper supply market, and the copper suppliers, mainly Chile seizing resource rents, are dominating the geopolitical competition for copper. According to above 2.1 risk detecting logic

analysis, risks brought by geo-core importers and geo-peripheral exporters are market price volatility and supply interruption. Because geo-core importers try to control the supply, thus distort the copper supply market; geo-peripheral exporters could increase mineral related taxes or fees, thus disturb routine copper supplies.

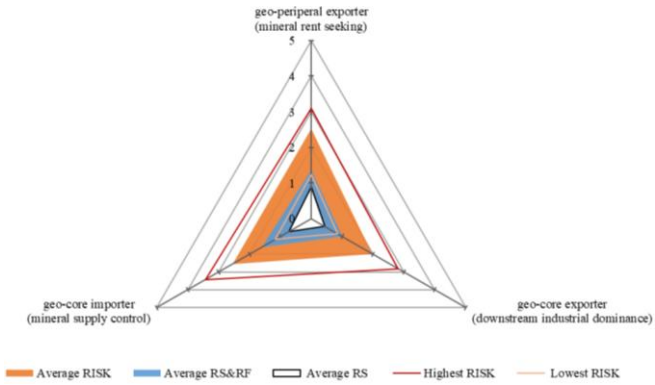

Fig. 4. Risk triangle of the risk of geopolitical competitions over copper.

V. Conclusion

The "conclusions" are a key component of the paper. It should complement the "abstract" and is normally used by experts to value the paper's engineering content. A conclusion is not merely a summary of the main topics covered or a re-statement of your research problem, but a synthesis of key points and, if applicable, where you recommend new areas for future research.

Geopolitical competitions over critical minerals have been keeping influencing mineral supply risks, lead to a more complicate market condition of it. The article construction a risk detecting framework to analyze it. The framework breaks down the risk into risk source, risk formation and risk transmission. Risk source captures the objective condition, means the chances to initiate geopolitical competitions, it basically depends on a country/region's market position. Risk formation explains forming potential of a geopolitical competition behavior, which viewed from the perspective of gaming, embodying both intentions and obstacles. Risk transmission tells the impact magnitude of geopolitical competition risks on mineral supply chains. A case study of copper is conducted. The results show that risk of geopolitical competition over copper is within the range of threshold risk level. The highest risk comes from geo-core importers, the lowest comes from geo-core exporters. The study identifies that the highest risk of geopolitical competition could from Chile, Peru, Kazakhstan, Indonesia, D.R. Congo, China EU, USA, Australia, and Canada. This research is a trial to detecting risk potentials of geopolitical competitions over critical minerals. In the future, more delicate and dynamic studies need to be down.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Wenhua Li conducted the research; Wenhua Li, Tsuyoshi Adachi and Juntao Wang analyzed the data; Wenhua Li wrote the paper; all authors had approved the final version.

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