Ensuring the security of the clean energy transition: Examining the impact of geopolitical risk on the price of critical minerals

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Outline

1. Research question

2. Data and Methodology

3. Results

Research question

Motivation

- How do geopolitical risks impact the price of critical minerals?
- Six critical minerals: aluminium, copper, nickel, platinum, tin, and zinc
- Conceptual framework in which the responsiveness of prices for critical minerals to geopolitical risk depends on the non-technical risk
- Geopolitical threats have a bigger effect on critical mineral prices than geopolitical acts
- Effects of geopolitical risk on the prices of critical minerals are time varying, with the Gulf War, 9/11 terrorist attacks and COVID-19 pandemic each having a significant effect
- Shocks due to geopolitical threats are generally bigger in magnitude than geopolitical acts, and prices respond more quickly to geopolitical threats

Research question

Motivation

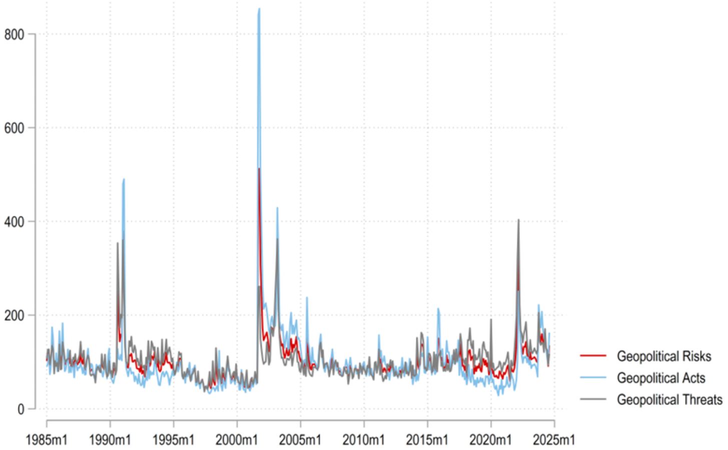
- No universal definition of critical minerals
- The EU states that “critical raw materials are raw materials of high economic importance for the EU, with a high risk of supply disruption due to their concentration of sources and lack of good, affordable substitutes”
- The Energy Act (2020) in the United States “defines a ‘critical material’ as: any non-fuel mineral, element, substance, or material that the Secretary of Energy determines: (i) has a high risk of supply chain disruption; and (ii) serves an essential function in one or more energy technologies, including technologies that produce, transmit, store, and conserve energy” (United States Department of Energy, 2024)
- The EU lists 34 critical minerals, while the United States lists 50 critical minerals

Motivation

- In practice, most metals, and minerals that are generally regarded as critical fall into one of three categories:
  - (a) minerals needed to facilitate the clean energy transition to carbon net-zero by 2050;
  - (b) minerals used in defense and security applications;
  - and (c) minerals employed in communication and entertainment technologies (see e.g., McNulty and Jowitt, 2021; Ramdoo et al., 2023).
- Geopolitical risk (GPR) is defined "as the risk associated with wars, terrorist acts, and tensions between states that affect the normal and peaceful course of international relations" (Caldara & Iacoviello, 2022)
- Given geopolitical rivalry to secure critical minerals (Khurshid et al. 2023; Vivoda, 2023; Vivoda & Mathews 2023) and the potential for violent conflict, supply chains are particularly susceptible to GPR (Dou & Xu, 2023; Renneboog, 2022)
- For instance, the Russia-Ukraine war is a source of GPR to critical mineral markets because Russia is a major producer of cobalt and nickel (Khurshid et al., 2023, 2024; Pata et al., 2024)

Research question

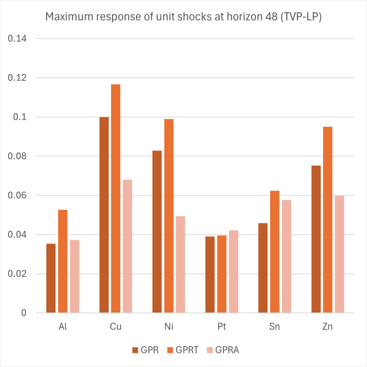
Figure 1. A topical question

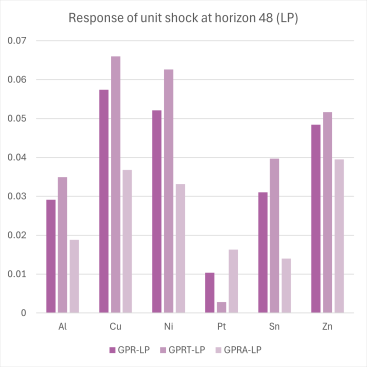


Notes: normalized to equal 100 over the period 1985-2019. The spikes correspond to the Gulf War, the 9/11 terrorist attacks followed by the Iraq War, and the War in Ukraine.

Research question: preview of the results

Figure 2. Long-term (48 month) responses to geopolitical risk, threats, and acts





Note: authors' calculations.

Research question

Literature overview

- Our contribution connects with several strands of literature
- One set of studies to which our paper is related are those on various aspects of prices for critical minerals: impact of global shocks (Considine et al. 2023; Miranda-Pinto et al. 2023) or government policies on prices for critical minerals (Dou et al., 2024; Romani & Casoli, 2024)
- Our study also contributes to the literature that has examined the implications of GPR for a range of energy and environment-related outcomes: effects of GPR on carbon emissions (Anser et al., 2021; Chen et al., 2024; Ding et al., 2023; Pata et al., 2023) or GPR on prices for natural resources and energy commodities (Aloui et al., 2023; Bouoiyour et al., 2019; Ding 2023a; Evrim Mandaci et al., 2023; Gkillas et al., 2022; Gong & Xu, 2022; Khurshid et al., 2024; Liu et al., 2019; Mignon & Saadaoui, 2024; Zhao, 2023)
- The extant literature on the effect of GPR on different aspects of prices for critical minerals is mostly recent and relatively scant
- Compared with these studies, our approach offers a more systematic analysis of the instability of impulse response functions (IRF) on a large array of critical minerals, which is also reflected in our results

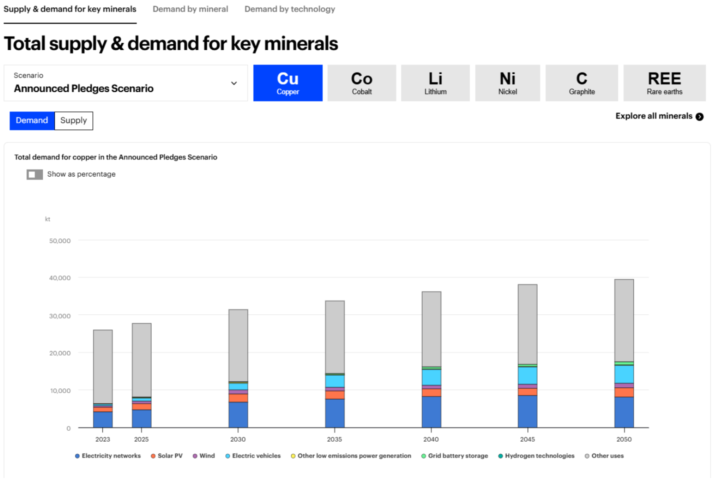
Research question

Literature overview

- Built on Vespignani and Smyth's (2024) recent work to consider how non-technical risk affects the extent to which GPR shocks lead to changes in prices of critical minerals
- Vespignani and Smyth (2024) show that 16 critical minerals, representing 90 percent of the total market value of the 50 critical minerals listed by the United States Department of Energy, had higher non-technical risks than a benchmark non-critical mineral composite, consisting of coal, gold and iron ore
- We examine the extent to which differences in non-technical risk, which will be reflected in the elasticity of the supply curve for each critical mineral, magnifies the effect of shocks to GPR on prices

Research question

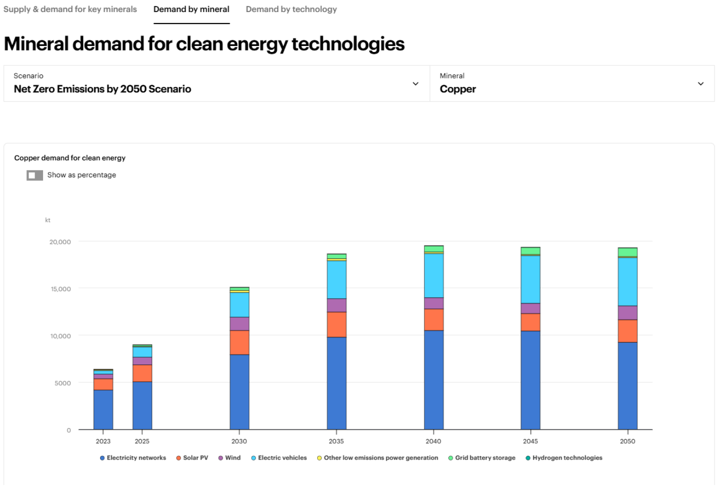
Figure 3. Demand for Copper



Notes: Data and projections from the International Energy Agency's critical minerals data explorer.

Research question

Figure 4. Demand for Copper by Technologies



Notes: Data and projections from the International Energy Agency's critical minerals data explorer.

Research question

Figure 5. Demand for Copper (Electricity Networks)

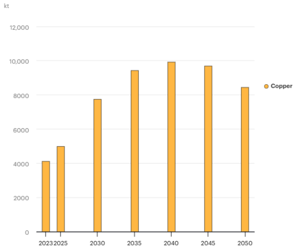
Mineral demand by clean energy technology

Scenario
Net Zero Emissions by 2050 Scenario

Technology
Electricity networks

Base Case | **Wider direct current (DC) technology development**

Mineral demand for Electricity networks in the Net Zero Emissions by 2050 Scenario, Wider direct current (DC) technology development



IEA. Licence: CC BY 4.0

Electricity networks

The accelerated development of electricity networks could explain about a fourth of the clean technology mineral demand in the Net Zero approach, adding strong momentum to copper demand. Since 2021, the IEA refined its mineral demand projections, with a more granular assessment by type of network, either overhead or underground, and voltage levels.

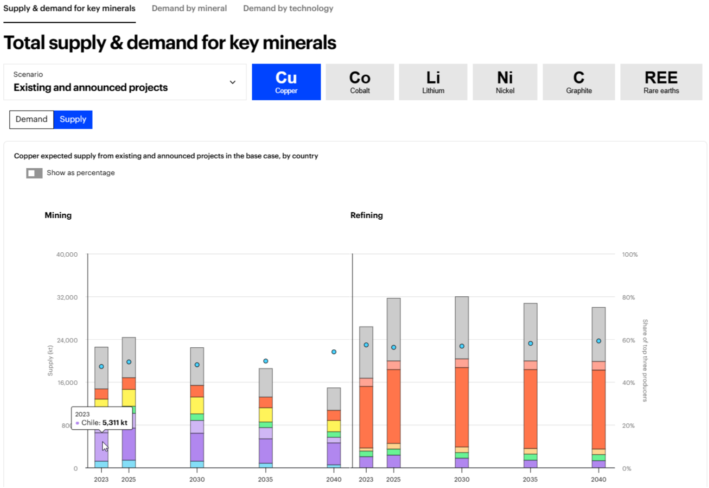
Wider direct current (DC) technology development

This case makes impact projections of a wider uptake of high-voltage DC systems - accounting for 50% of new transmission lines and 30% of distribution lines by 2040 - which would reduce combined demand for copper and aluminium. These systems use only two wires, which implies a direct saving on metal consumption of one-third compared to alternative current systems. High voltage DC systems are also capable of transporting more electricity (theoretically up to 3.5 times more).

Notes: Data and projections from the International Energy Agency's critical minerals data explorer.

Research question

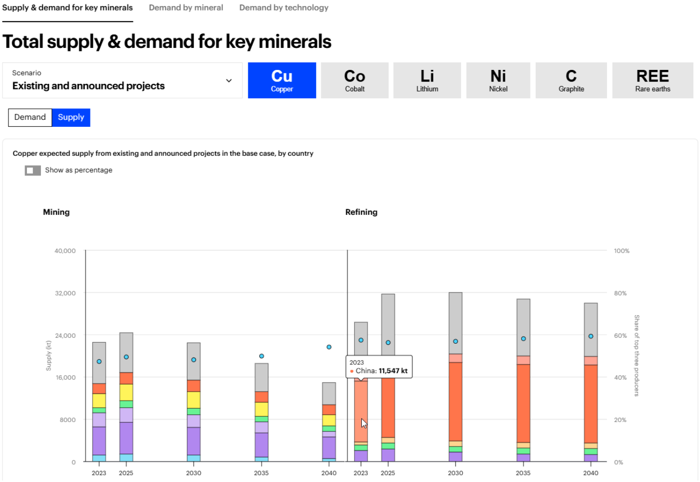
Figure 6. Copper (Mining - Chile)



Notes: Data and projections from the International Energy Agency's critical minerals data explorer. US in light blue, Peru in light violet, Russia in green, Democratic Republic of Congo in yellow, China in orange and Japan in light orange.

Research question

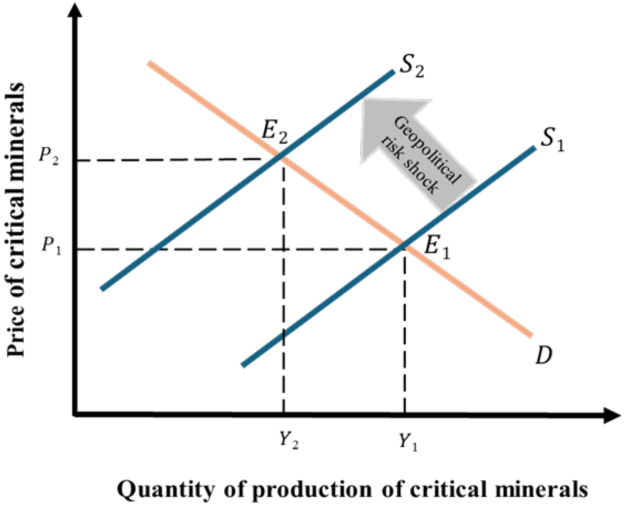
Figure 7. Copper (Refining - China)



Notes: Data and projections from the International Energy Agency's critical minerals data explorer. US in light blue, Peru in light violet, Russia in green, Democratic Republic of Congo in yellow, China in orange and Japan in light orange.

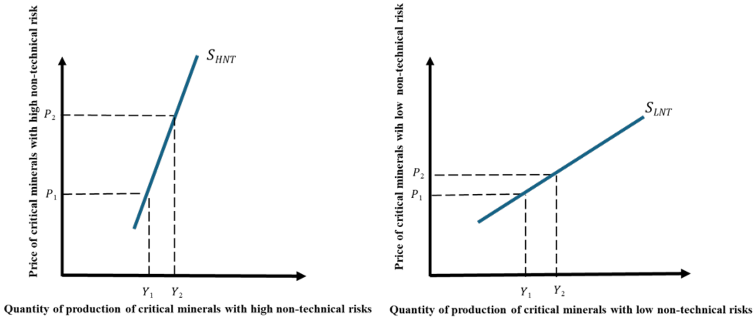
Research question

Figure 8. The impact of geopolitical risk shocks on critical mineral markets



Research question

Figure 9. How high vs. low critical mineral prices respond to geopolitical risk shocks



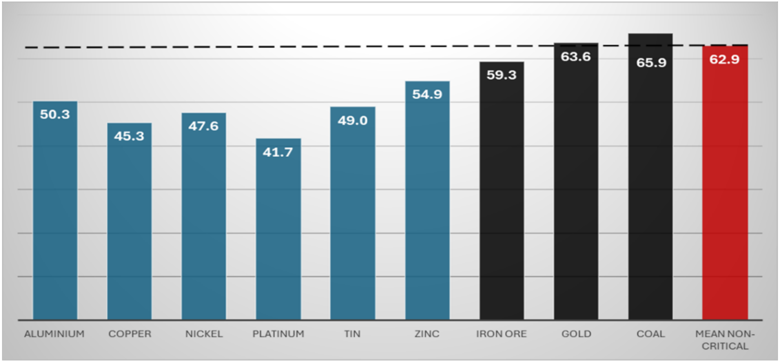
Research question

Non-technical risk premiums

- Vespignani and Smyth (2024) proposed a methodology to estimate non-technical risks and non-technical risk premiums
- $Non-technical\,risk = \sum_i^n w_{c,m} \times s_c$
- $w_{c,m}$ is the proven reserves of critical mineral m in country c as a percentage of the world's proven reserves of minerals and S is the investment attractiveness index score for country c from the Annual Survey of Mining Companies conducted by the Fraser Institute (2022)
- We use the non-technical risk scores to calculate the non-technical risk premium, which is the critical mineral non-technical risk expressed as a percentage of the non-technical risk of the non-critical front-ended mineral benchmark
- Consistent with Vespignani and Smyth (2024), we use the average non-technical risk of coal, gold and iron ore to represent the non-critical front-ended mineral benchmark
- $Non-technical\,risk == \frac{(IAI_{NC} - IAI_C)}{IAI_{NC}}$
- Where IAI_{NC} and IAI_C is the investment attractiveness index and NC and C denote non-critical minerals and critical minerals, respectively

Research question

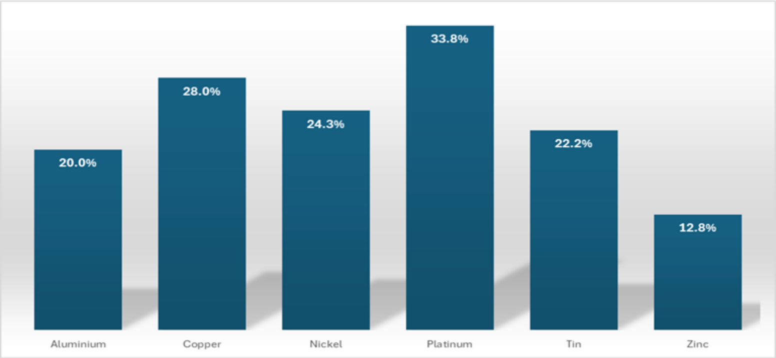
Figure 10. The non-technical risk scores of selected critical minerals (2023)



Note: authors' calculations. Lower values represent a lower investment attractiveness index and higher non-technical risk for the relevant mineral.

Research question

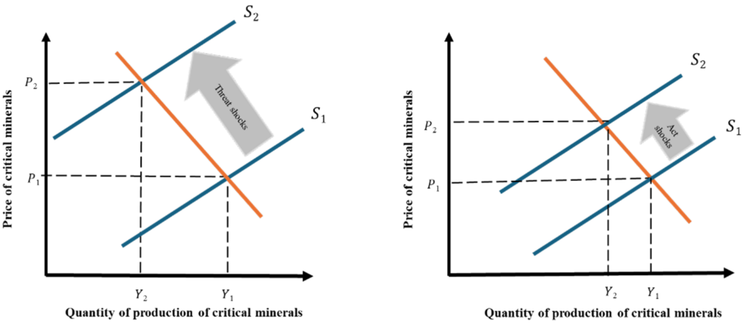
Figure 11. The non-technical risk premiums of selected critical minerals (2023)



Note: authors' calculations. The non-technical risk premium reflects the additional risk in the project development of each critical mineral compared to the benchmark of iron ore, gold, and coal.

Research question

Figure 12. The impact of geopolitical threats and acts on selected critical minerals



Note: authors' calculations. The threats are shown in the Figure on the left, the acts are shown on the right.

Outline

1. Research question

2. Data and Methodology

3. Results

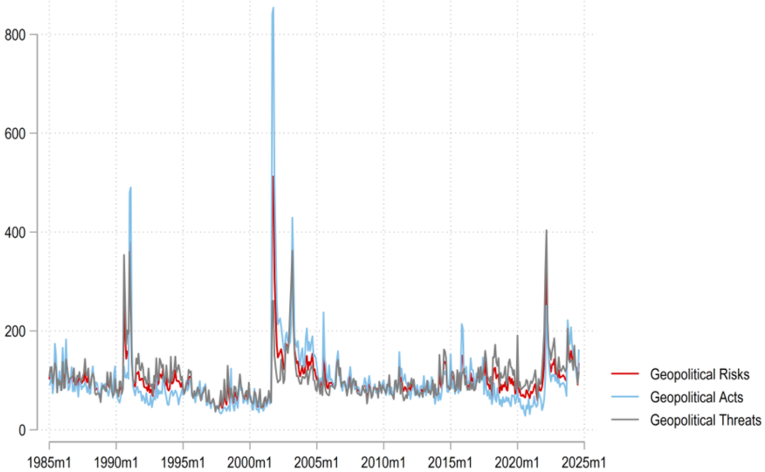
Data and Methodology

Data

- Monthly prices from January 1985 to January 2024 for aluminium, copper, nickel, platinum, tin, and zinc ($T = 476$)
- The prices for these six critical minerals were obtained from the World Bank's "pink sheet" and we used data for all critical minerals available from this source
- The data on economic activity is sourced from Baumeister et al. (2022), while information on GPR, geopolitical actions, and threats is sourced from Caldara and Iacoviello (2022)
- Global inflation data is obtained from the Federal Reserve Bank of Dallas, Database of Global Economic Indicators, which is based on Garcia-Martinez et al. (2015).

Data and Methodology

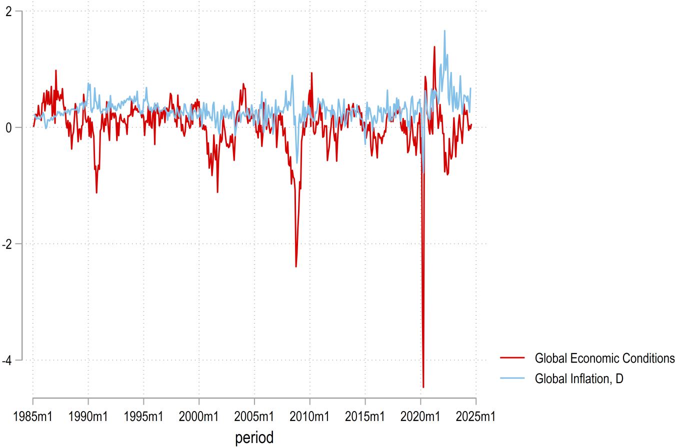
Figure 13. Data description - GPR



Note: normalized to equal 100 over the period 1985-2019. The spikes correspond to the Gulf War, the 9/11 followed by the Iraq War, and the War in Ukraine.

Data and Methodology

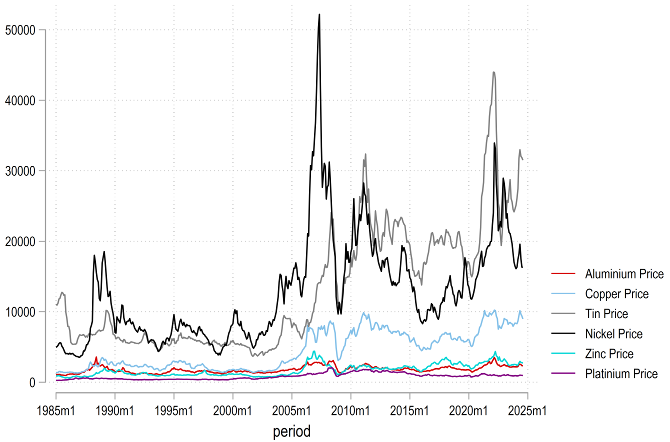
Figure 14. Data description - GECON and Inflation



Note: negative values for GECON indicate deterioration of Global Economic Conditions, see Baumeister (ReStat, 2022).

Data and Methodology

Figure 15. Data description - Commodity prices



Note: authors' calculations. The critical mineral prices are expressed in US dollar per metric ton, except for the platinum price, expressed in US dollar per troy oz.

Data and Methodology

Empirical approach

- We use the TVP-LP approach, pioneered by Inoue et al. (2024), to examine the effects of GPR shocks on critical mineral prices.
- Methodologically, the LP approach (Jordà, 2005) has several advantages, including estimation by single equation OLS at each horizon, a simple inference for impulse response coefficients, the effects being local to each horizon (i.e., no cross-period restrictions) and the estimation of very nonlinear and flexible models being straightforward in this setup
- In addition, Olea Montiel et al. (2024, p.2) have recently provided "a formal proof of Jordà's claim that conventional LP confidence intervals for impulse responses are surprisingly robust to misspecification"
- Regarding our research question, all features of the TVP-LP approach enable us to provide time-varying dynamic evidence on the causal impact of GPR shocks

Data and Methodology

Empirical approach

- We examine the effect of a one-unit identified geopolitical risk shocks (ϵ_{gpr}) on the price of critical minerals (cms). Thus, we can formulate the TV-LP approach as follows:

$$cms_{t+h} = c_{t+h} + \beta_{h,t+h}\epsilon_{gpr} + \sum_{j=1}^{12} \alpha'_{j,t+h}\mathbf{z}_{t-j} + v_{t+h} \quad h = 0, 1, \ldots \tag{1}$$

$$\mathrm{IRF}(h) = \beta_{h,t+h}$$

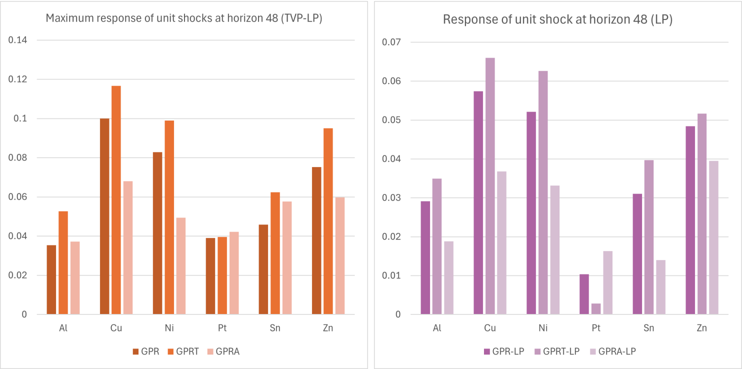
- where $\mathbf{z} = (cms, gecon, ginf, \epsilon_{gpr})'$. The parameter of interest is the time-varying impulse response $\beta_{h,t+h}$. The explained variable, the price of the six critical minerals, is designated by cms. We use successively the price of aluminium, copper, nickel, platinum, tin and zinc, as the explained variable. h, is the horizon; ϵ_{gpr} is the impulse variable (SVAR-identified geopolitical risk shocks); $\mathbf{z}$ is a vector of control variables; IRF, stands for the impulse response function and v, is the error term.
- The series of GPR shocks, ϵ_{gpr}, are obtained for each critical mineral and the different GPR index using a SVAR(12) and the following recursive ordering: $cms, gecon, ginf, gpr$; where cms is the price of different critical minerals and gpr is alternatively the GPR index, the GPR Threat index or the GPR Act index. Overall, we have six critical minerals and three GPR indexes. Thus, we have 18 series of different GPR shocks.

Outline

1. Research question
2. Data and Methodology
3. Results

Results

Figure 16. Long-term (48 month) responses to geopolitical risk, threats, and acts



Note: authors' calculations.

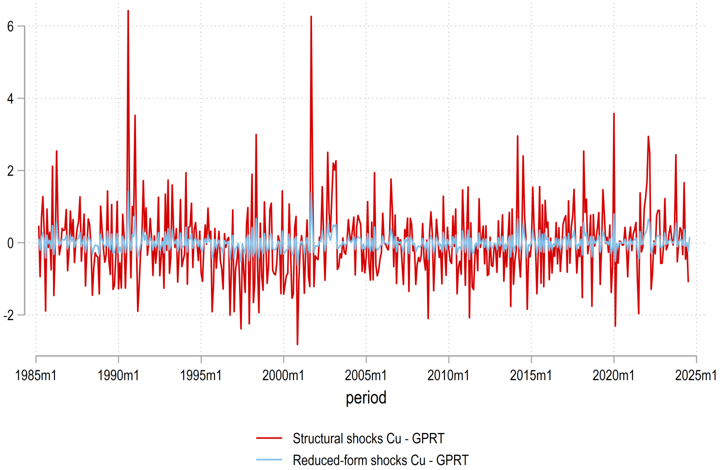
Results

Focus on Copper

- According to The Economist (Mar 24th 2025): *"The mineral facing the biggest disruptions is copper, which is required in much larger volumes. Miners are unlikely to be able to dig up enough of the stuff to keep up with growing demand. Politicians obsess over rare earths. But a much more common metal is the real problem."*
- Source: https://www.economist.com/graphic-detail/2025/03/24/a-visual-guide-to-critical-materials-and-rare-earths

Results for Copper

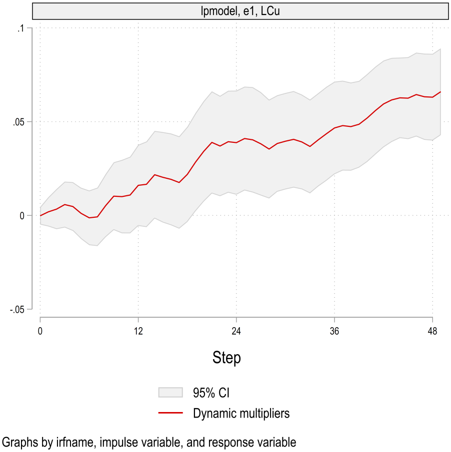
Figure 17. Structural and reduced form shocks



Note: authors' calculations.

Results for Copper

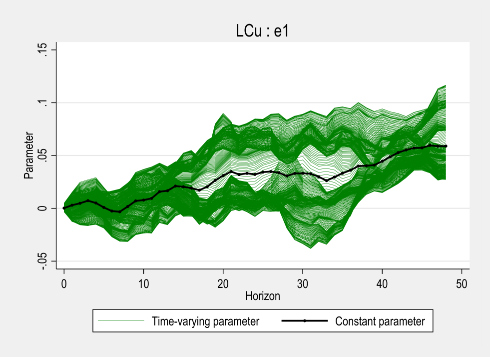
Figure 18. Response of individual critical minerals to geopolitical shock threats (GPRT)



Note: authors' calculations.

Results for Copper

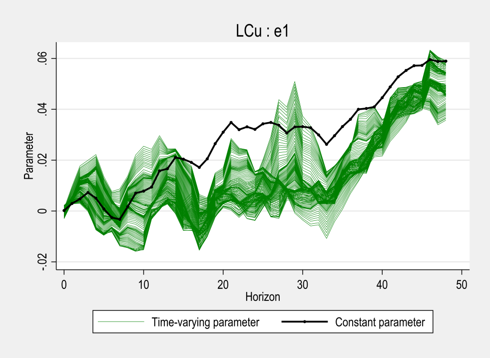
Figure 19. Response of individual critical minerals to geopolitical shock threats (GPRT) - Time-varying response



Note: authors' calculations.

Results for Copper

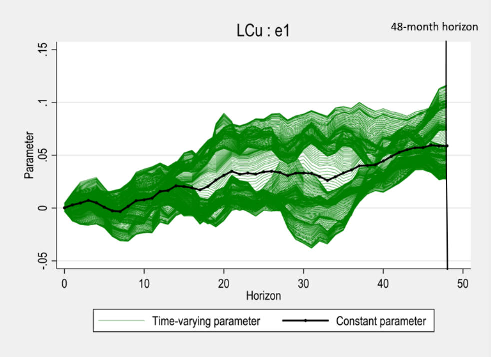
Figure 20. Response of individual critical minerals to geopolitical shock threats (GPRT) - After GFC



Note: authors' calculations.

Results for Copper

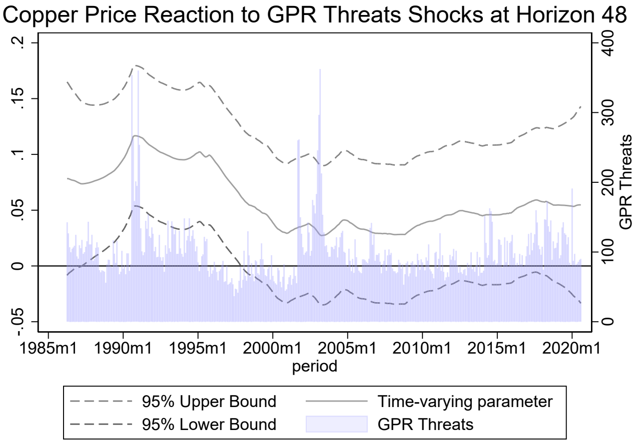
Figure 21. Response of individual critical minerals to geopolitical shock threats (GPRT) - Time-varying response



Note: authors' calculations.

Results for Copper

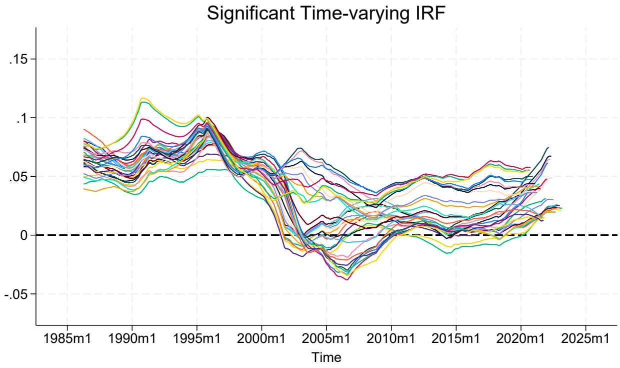
Figure 22. Response of individual critical minerals to geopolitical shock threats (GPRT) - Time-varying response



Note: authors' calculations. The gray curve in this graph corresponds to the black line in the previous figure, the path estimator at the 48-month horizon for the impulse response function. We can see that elasticities of the copper price to geopolitical threats fluctuate between 5 percent and 12 percent.

Results for Copper

Figure 23. Response of individual critical minerals to geopolitical shock threats (GPRT) - Significant IRF at different horizons



Note: authors' calculations. We plot the set of impulse response functions that have a positive value for the maximum of their lower confidence band.

Final thoughts

Key takeaways

- The traditional focus of the literature on energy security has been on fossil fuels
- In this paper, we employed constant and time-varying parameter local projection (TVP-LP) regression models, recently proposed by Inoue et al. (2024), to examine the effect of GPR on prices of aluminium, copper, nickel, platinum, tin, and zinc
- We observe considerable time varying effects in the response of prices of critical minerals to GPR shocks
- Our results have important implications for our understanding of the role of critical minerals in ensuring energy security and realizing the clean energy transition
- Importantly, they suggest that the effect of GPR (including geopolitical acts and threats) on the prices of critical minerals can be mitigated through reducing non-technical risk