Critical Minerals, Geopolitics, and the Green Transition

Tomás Domínguez-Iino
UChicago

Jonathan Elliott
Johns Hopkins

Allan Hsiao
Stanford

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Critical minerals will power the green transition

- Lithium, nickel, cobalt, and other minerals
  - Critical for producing advanced batteries
  - Concentrated geographically, but traded globally

- What are the global impacts of national mineral policy?
  - Policy spillovers, supply disruptions, and mineral cartels
  - With implications for geopolitics and green adoption

Bloomberg

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Markets | Hyperdrive

Indonesia Weighs Deep Cuts to Nickel Mining to Boost Prices

- Energy ministry considering big reduction, people familiar say
- Prices of the battery metal have slumped on booming supply

By Eddie Spence and Faris Mokhtar
December 19, 2024 at 6:55 AM GMT-3

BENCHMARK SOURCE
Supply Chain Intelligence for the Energy Transition

Australian lithium supply cut by 15% due to low spodumene prices

14th November 2024

Fastmarkets

Cobalt export quotas: DRC sets limits to rebalance global supply

The Democratic Republic of Congo has introduced cobalt export quotas following the suspension period, setting limits on shipments while outlining future allocations. The policy is designed to balance global supply and demand while supporting the country's ambition to develop domestic processing capacity.

September 22, 2025

MINING.COM

South America looks at creating "lithium OPEC"

Cecilia Jamasmie | March 6, 2023 | 6:53 am Intelligence News Suppliers & Equipment Latin America Lithium

This paper

- Concentrated endowments give countries market power
  - But exercising market power may induce switching
- Geopolitics
  - Affects all mineral-endowed countries
- Green adoption
  - Affects all battery technologies

Contributions

- Concentration in global energy markets with **complementarity**

  Farrokhi (2020), Bornstein et al. (2023), Abuin (2024), De Cannière (2024), Kellogg (2024)

- Geopolitics of market power with **policy spillovers**

  Antràs & Chor (2013), Ossa (2014), Farrell & Newman (2019), Clayton et al. (2026)

- Dynamic estimation with **cost data**

  Hall (1978), Scott (2013), Asker et al. (2024), Clausing et al. (2025), Hsiao (2026)

Data

Critical minerals

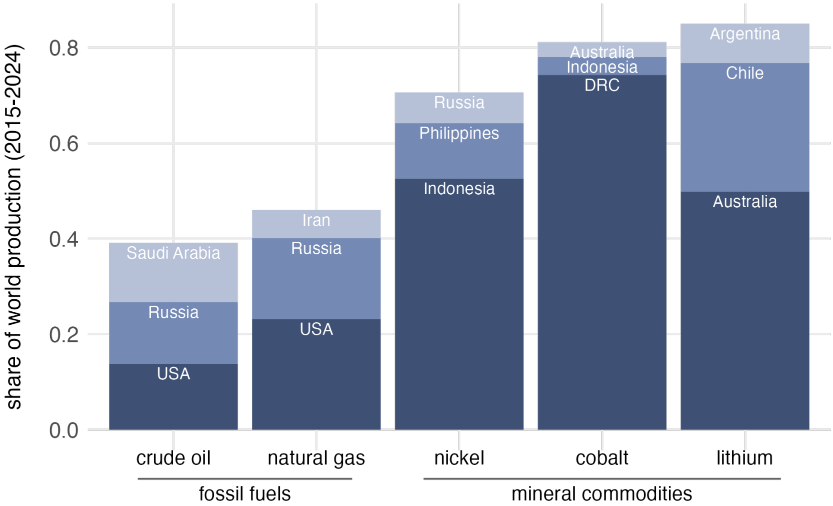
- Energy technology inputs with supply disruption risk (Energy Act of 2020)
  - Separate: rare earths for national security purposes

EV battery % of world demand					
Lithium	Cobalt	Nickel	Graphite	Copper	Manganese
65	45	11	10	4	1

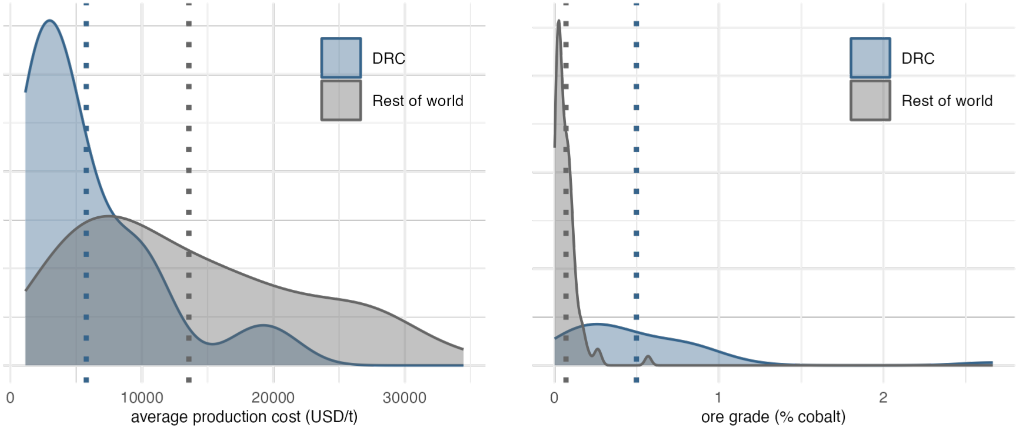
Data

- Annual mineral production by mine (GlobalData, S&P, Benchmark Minerals)
  - Capacity, ore grade, ownership structure, mine type, mining method
- Quarterly battery demand by type-make-model-country (Rho Motion)
  - E.g., NCM batteries used in Tesla Model S production in the US in Q1 2024
- Battery-mineral "recipes" (Argonne National Laboratory)

Mineral supply is geographically concentrated

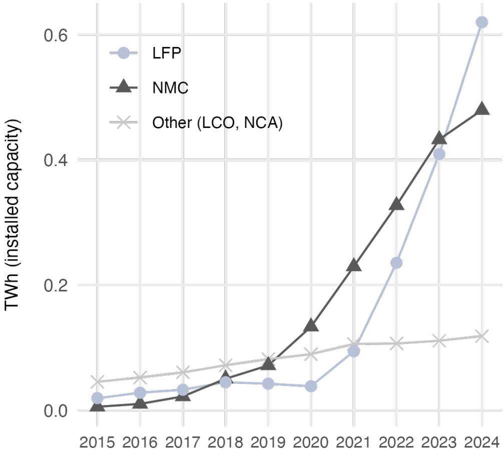


With heterogeneous costs across mines



Mineral recipes vary by battery type

	nickel	lithium	cobalt
LFP	-	0.09	-
NCA	0.65	0.1	0.12
NMC	0.47	0.11	0.18



Theory

Market power

- **Minerals** $\mathcal{M}$ with supply s^m
  - ℓ: lithium produced only by country ℓ
  - n: nickel produced only by country n
- **Technologies** $\mathcal{J}$ with demand d_j
  - L: lithium-heavy
  - N: nickel-heavy
- **Recipes** $\mathcal{R}$
  - Yields derived demand $d^m(d_L, d_N)$

Complementarity

- Own-price demand elasticity: $\frac{\partial d^n}{\partial p^n} < 0$
- Cross-price demand elasticity: $\frac{\partial d^\ell}{\partial p^n} <> 0$
  - **Complementarity** $(<)$ from joint use in technologies L and N
  - **Substitutability** $(>)$ from switching to technology L, which uses more ℓ
- On net, lithium and nickel can be gross complements or substitutes

Geopolitics and green adoption

- Country n restricts s^n, so $p^n \uparrow$
- Geopolitical spillovers
  - Complements: less d^ℓ, so $p^\ell \downarrow$ (hurts)
  - Substitutes: more d^ℓ, so $p^\ell \uparrow$ (helps)
- Green adoption in aggregate
  - Complements: higher p^n but lower p^ℓ
  - Substitutes: higher p^n and p^ℓ, so $d_L + d_N \downarrow$ (hurts)

Empirical model

Same

- Demand d_j for technologies
- Supply s^m of minerals
- Recipes R_j^m from electrochemistry
- Prices (p^m, p_j) in equilibrium

Additional

- Many countries, technologies, minerals
- Heterogeneous endowments across countries
- Heterogeneous policy across countries
- Dynamic supply of minerals

Demand

Demand by technology j, region k, year t

- Almost ideal demand system: expenditure shares w, prices p, translog P

$$w_{jkt} = \alpha_{jt} + \beta_j \log \frac{x_{kt}}{P_t} + \sum_{j'} \gamma_{jj'} \log p_{j't} + \varepsilon_{jkt}$$

$$\log P_t = \sum_j \alpha_{jt} \log p_{jt} + \frac{1}{2} \sum_{jj'} \gamma_{jj'} \log p_{jt} \log p_{j't}$$

- Recipes R give demand by mineral m

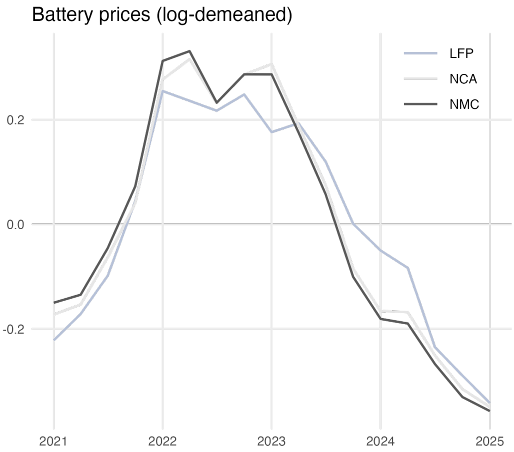
$$d^{mkt} = \sum_j R_j^m d_{jkt}, \quad d_{jkt} = \frac{w_{jkt} x_{kt}}{p_{jt}}$$

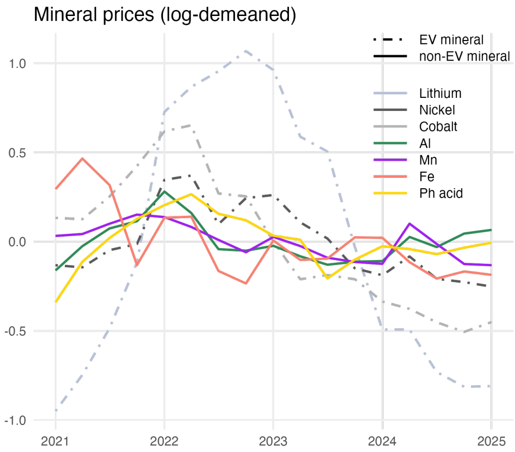
Estimation

$$z_{jt} = \sum_{m \in \mathcal{M}'} R_j^m p^{mt}, \quad \mathcal{M}' = \{\text{Al, Mn, Fe, Ph acid}\}$$

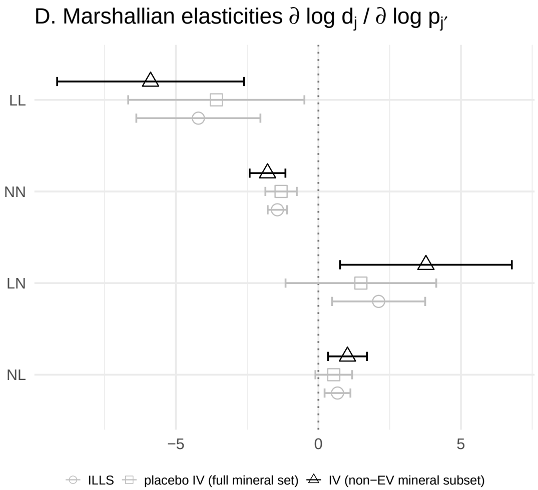
- Instrument for technology prices with non-EV mineral prices as cost shifters
  - Relevance: mineral p^{mt} affect technology p_{jt} through recipes R_j^m
  - Exclusion: EVs are less than 3% of non-EV mineral demand

Price variation





Elasticities



- IV $>$ OLS as expected
  - But only with $\mathcal{M}' \subset \mathcal{M}$
- $LL > NN$ reflects quality of L
  - Shorter driving range
  - More price-sensitive customers
- LN and NL capture switching

Supply

Supply s^{it} by mineral $m(i)$, mine i, year t

- Simplest model: marginal revenues and costs (r^{it}, c^{it})
  - Under myopia, just compare r^{it} and c^{it}
  - Under $MC = AC$, our cost data are c^{it}
  - Under price-taking, our price data are r^{it}

- Cost data $\rightarrow$ empirical supply curves
  - If $p^t > c^{it}$, produce at capacity
  - If $p^t < c^{it}$, produce zero

Problems

- Myopia shuts down **dynamics**
  - Despite finite reserves and ore grade that falls with extraction
- $MC = AC$ shuts down **cost convexity**
  - Predicts all-or-nothing production and discrete jumps
- We make progress on both
  - But keep price-taking by mines (with market power by country)

Dynamics with cost convexity

Euler condition

$$p^t - c^{it} = \beta \mathbb{E}^{it}[p^{t+1} - c^{it+1}]$$

Marginal cost

$$\bar{c}^{it} = a + bu^{it} + e^{it}$$

Average cost

$$c^{it} = a + \frac{b}{2}u^{it} + e^{it}$$

- Production s^{it} depletes reserves $S^{it+1} = S^{it} - s^{it}$
    - Shadow cost of production today (Hotelling)
    - Convex in utilization $u^{it} = s^{it}/\bar{s}^i$ of capacity $\bar{s}^i$
- We observe average costs as **data**
    - Estimate remaining cost structure (a, b)
    - **Endogeneity** from unobserved cost shocks e^{it}

Differencing

- **Euler condition** in differences with expectational error

$$\underbrace{\Delta p^t}_{p^t - \beta p^{t+1}} = \Delta a + b \Delta u^{it} + \Delta e^{it} + \underbrace{\eta^{it}}_{\mathbb{E}^{it}[x^{it+1}] - x^{it+1}}$$

- **Average costs** in differences

$$\Delta \bar{c}^{it} = \Delta a + \frac{b}{2} \Delta u^{it} + \Delta e^{it}$$

- We subtract to eliminate Δe^{it}

$$\Delta p^t - \Delta \bar{c}^{it} = \frac{b}{2} \Delta u^{it} + \eta^{it}$$

Estimation

1. Estimate b with lagged instruments $u^{it} \in \mathcal{J}^{it}$

$$\Delta p^{t} - \Delta \bar{c}^{it} = \frac{b}{2} \Delta u^{it} + \eta^{it}$$

2. Recover a and unobserved costs e^{it}

$$\bar{c}^{it} - \frac{\hat{b}}{2} u^{it} = a + e^{it}$$

Intuition

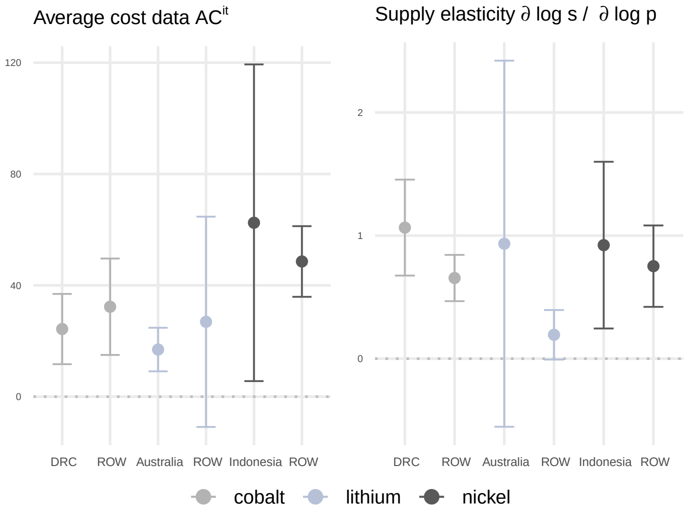
$$u^{it} = \frac{2}{b}(p^t - \bar{c}^{it} - \bar{\eta}^{it}), \quad \frac{\partial \log s^{it}}{\partial \log p^t} = \frac{p^t}{p^t - \bar{c}^{it} - \bar{\eta}^{it}}$$

- Supply curve still reflects cost data $\bar{c}^{it}$
  - But have smooth responses to prices p^t
  - Dynamics through $\bar{\eta}^{it} = \sum_{t'=0}^{\infty} \beta^{t'} \eta^{it+t'}$ for $\eta^{it}(p^{t+1})$

Additional features

- Ore quality that degrades with extraction
  - Richer dynamics as production today raises costs tomorrow
- Heterogeneity in cost parameters
  - Richer cost structure than common (a, b)
- Measurement error in average costs
  - Enters on the LHS, avoiding bias

Elasticities



- Top producers are largely more elastic
- Lower utilization rates, so have room to grow
- Consistent with higher cost convexity, despite lower average costs

Counterfactuals

Equilibrium prices

- Mineral prices clear markets (with non-battery demand δ^{mt})

$$\sum_{i \in \mathcal{I}^{mt}} s^{it} = \sum_{j} R_j^m d_{jt} + \delta^{mt}$$

- Technology prices from mineral prices (with refining/manufacturing markups μ_{jt})

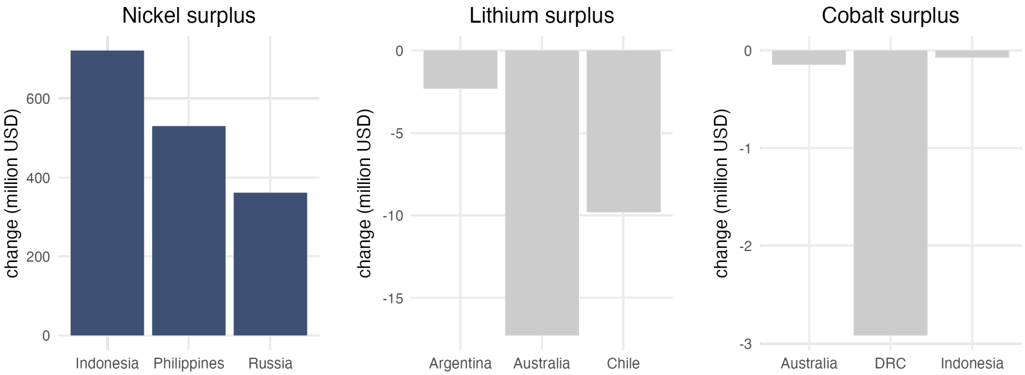
$$p_{jt} = \sum_{m} R_j^m p^{mt} + \mu_{jt}$$

1. Supply chain vulnerability

	Baseline share (%)	Price change (%Δ)
Indonesia (Ni)	35	67
Australia (Li)	45	241
DRC (Co)	71	774

- Remove the largest producer, solve for equilibrium price changes
  - Bigger for lithium: inelastic demand due to universal use
  - Biggest for cobalt: DRC has major ore grade advantage

2. Unilateral policy: Indonesian nickel and geopolitics



- Indonesia restricts nickel: substitutes win and free-ride, complements lose

2. Unilateral policy: Indonesian nickel and green adoption

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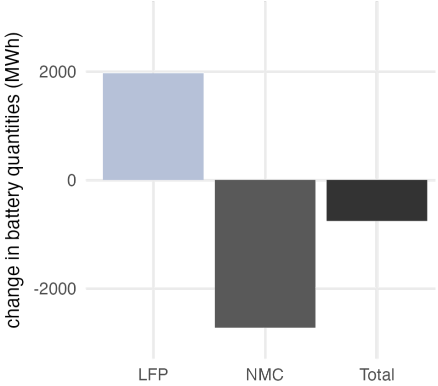
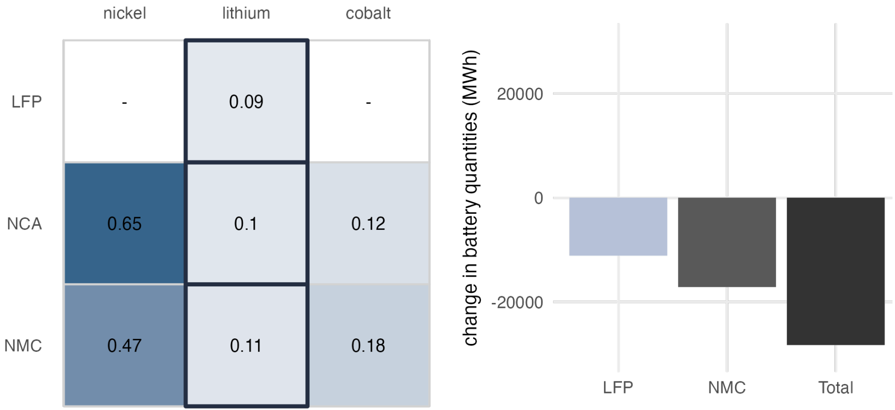


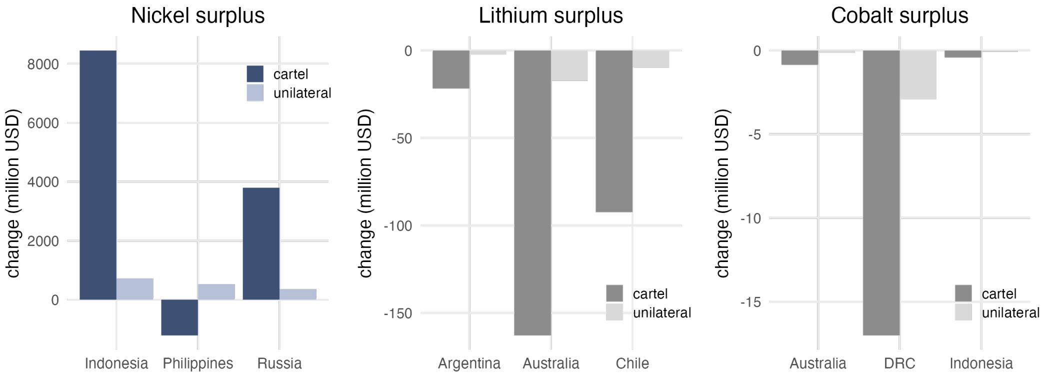
- Aggregate adoption falls, but with dampening from switching

2. Unilateral policy: Australian nickel and green adoption



- Aggregate adoption falls greatly, as lithium is a universal input

3. Cartel policy: OPEC for nickel (ONEC)



- Cartel restricts nickel: bigger cut, bigger effects, but Philippines loses

Summary

- Critical minerals will power the green transition
- Mineral resources are **concentrated** and **interdependent**
  - With implications for geopolitics and green adoption