Critical Minerals, Geopolitics, and the Green Transition

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Critical minerals will power the green transition

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

- Resource concentration gives countries market power

Bloomberg

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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

- What is the impact of upstream market power on…
  - downstream battery adoption? (green transition)
  - consumer and producer welfare? (geopolitics)
- Dynamic equilibrium model of global mineral market
  - Estimated using universe of mine-level data
- Minerals are complementary inputs in battery production
  - Distinct from single-resource settings (e.g., OPEC)

Key takeaways

- Market power with complements $\neq$ market power with substitutes
- Complementarity flips the sign of geopolitical incidence
  - Saudi oil cut $\rightarrow$ US oil wins (substitutable oil varieties)
  - Indonesian Ni cut $\rightarrow$ Australian Li loses (complementary minerals)
- Complementarity flips the role of market power for green transition
  - Within-mineral consolidation $\rightarrow$ raises markups (slower)
  - Across-mineral consolidation $\rightarrow$ eliminates double markups (faster)

Outline

1. Background
2. Model
3. Counterfactuals

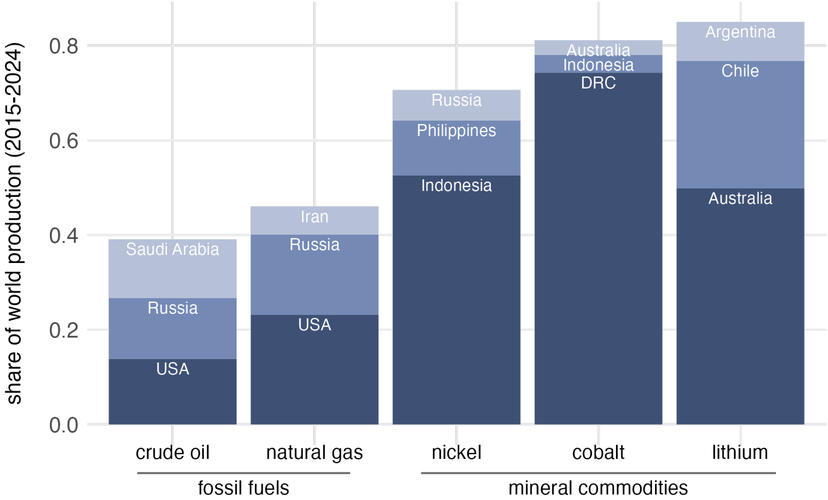
Critical minerals

- Minerals with low substitutability + high supply risk
  - Focus on criticality for energy transition: lithium, cobalt, nickel
  - Separate national security purposes: rare earths
- Focus on battery demand from EV sector
  - accounts for over 80% of annual battery installations

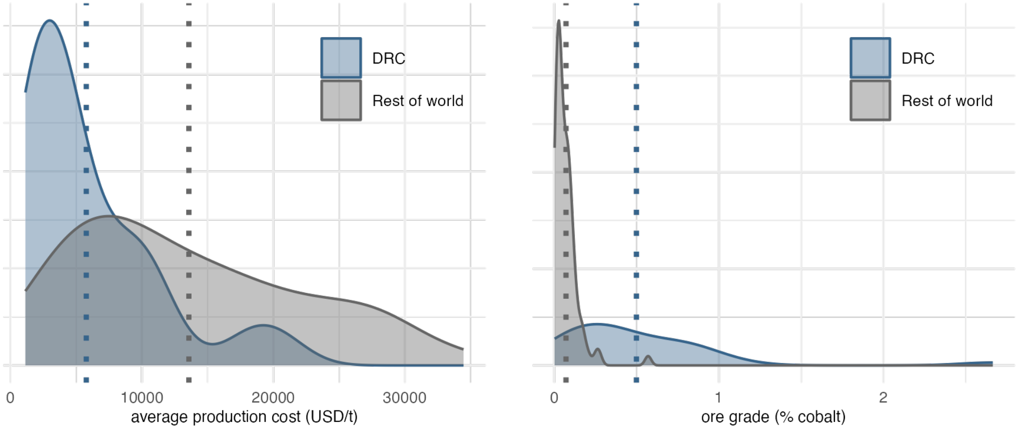
Data

- Mineral supply: mine-level production (GlobalData, S&P, BMI)
  - Covers 95%, 94%, 88% of world production for lithium, cobalt, nickel
- Battery demand: EV producer-level consumption (Rho Motion)
  - E.g., Tesla's purchases of NMC batteries for Model S production in US, Q1 2021
- Battery-mineral "recipes" (Argonne National Laboratory)
  - Maps battery demand to mineral demand

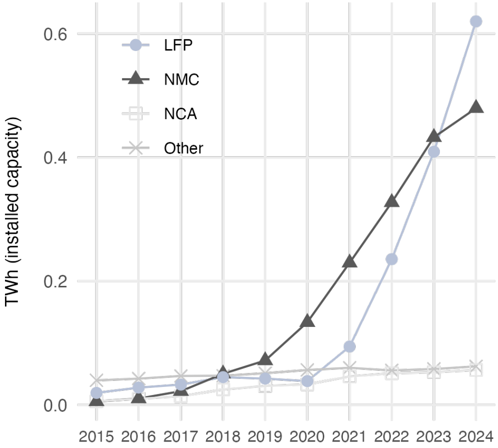
Mineral supply is geographically concentrated



With heterogeneous costs across mines



Mineral recipes vary by battery technology



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

kg mineral/kWh capacity

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Environment

- **Minerals** $m \in \mathcal{M}$ with supply s^m
  - Dynamic mine-level extraction
- **Batteries** $j \in \mathcal{J}$ with demand d_j
  - EV manufacturers switch across battery types (substitution)
  - Each battery type uses minerals in fixed proportions r_j^m (complementarity)
- **Equilibrium** in the global mineral market
  - Recipes r_j^m map $d_j \to d^m$ and $p_{jt} = \sum_m r_j^m p^{mt}$

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   - Demand
   - Supply
3. Counterfactuals

EV manufacturer demand for batteries

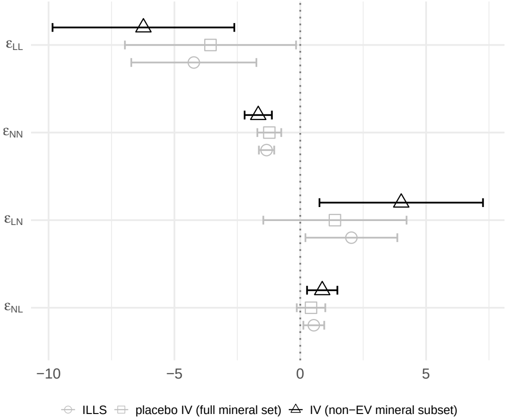
- Goal is to allow flexible substitution across battery types $j \in \mathcal{J}$ (AIDS)
  - EV manufacturer in region k, year t with battery budget X_{kt}
  - Expenditure shares w_{jkt}, prices p_{jt} w/index P_t, substitution $\gamma_{jj'}$

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

- **Endogeneity** from demand shocks $\varepsilon_{jkt} \rightarrow$ address with cost-shifters
  - Use prices of non-EV mineral inputs (e.g., phosphoric acid)
  - Relevant (via recipes) and excluded ($>$97% of demand is non-EV)

Results: Battery demand elasticities

$$\epsilon_{jj'} \equiv \partial \log d_j / \partial \log p_{j'}$$



- Own-price elasticities $\epsilon_{jj} < 0$
- Cross-price elasticities $\epsilon_{jj'} > 0$
- Substitution/complementarity forces
  - battery switching $(\epsilon_{jj'})$ vs battery-mineral recipes (r_j^m)

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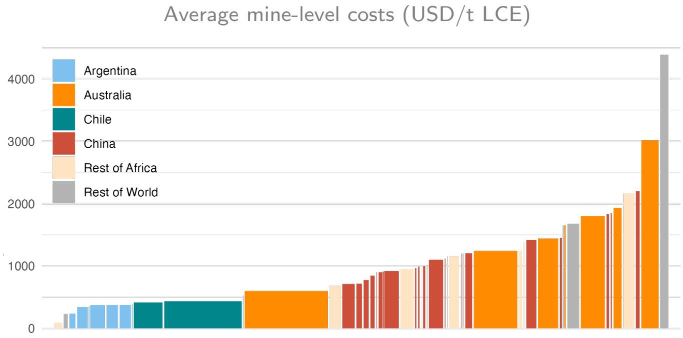
Motivation

- We could construct supply curves from our average cost data



- But requires strong assumptions: myopia $(mr^{it} = mc^{it})$ + linear costs $(mc^{it} = ac^{it})$
  - Our model relaxes these assumptions with **dynamics** + **cost convexity**

Dynamics with cost convexity

Euler/Hotelling equation

$$mr^{it} - mc^{it} = \beta\mathbb{E}^{it}[mr^{it+1} - mc^{it+1}]$$

Marginal $\neq$ Average cost

$$mc^{it} = \widetilde{mc}^{it}(x^{it};\kappa) + \varepsilon^{it}$$
$$ac^{it} = \widetilde{ac}^{it}(x^{it};\kappa) + \varepsilon^{it}$$

- Mine i extracts raw ore x^{it} given its reserves, costs, expectations
  - Shadow cost of extraction (finite reserves)
  - Cost function $\widetilde{C}(x;\kappa)$ with convexity parameter κ (e.g., $x + \kappa x^2$)
  - Unobserved cost shocks ε^{it} (shows up in both mc and ac)

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- **Endogeneity** from ε^{it} when estimating κ $\rightarrow$ exploit ac^{it} data to purge ε^{it}

Endogeneity

Euler equation in PV-differences $(\Delta x^{it} = \beta x^{it} - x^{it-1})$ with expectational error (η^{it})

$$\Delta mr^{it} = \underbrace{\Delta \widetilde{mc}^{it}(x^{it};\kappa) + \Delta\varepsilon^{it}}_{\text{Cov}(x^{it},\varepsilon^{it})<0 \rightarrow \text{endogeneity}} + \eta^{it}$$

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Use average cost definition to invert shocks from observables (ac^{it}, x^{it})

$$\Delta\varepsilon^{it} = \Delta ac^{it} - \Delta\widetilde{ac}^{it}(x^{it};\kappa)$$

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$$\Delta\varepsilon^{it} = \Delta ac^{it} - \Delta\widetilde{ac}^{it}(x^{it};\kappa)$$

Substitute to eliminate $\Delta\varepsilon^{it}$

$$\underbrace{\Delta mr^{it} - \Delta ac^{it}}_{\text{data}} = \underbrace{\Delta\widetilde{mc}^{it}(x^{it};\kappa) - \Delta\widetilde{ac}^{it}(x^{it};\kappa)}_{\text{known function of } x^{it}} + \eta^{it}$$

Estimation

Baseline specification $\widetilde{C}(x) = \alpha x + \frac{1}{2}\kappa x^2$ with grade heterogeneity $mr^{it} = p^{mt} g^{it}$

$\rightarrow$ extensions: other $\widetilde{C}(x)$, ore degradation, capacity heterogeneity, x/ε interactions

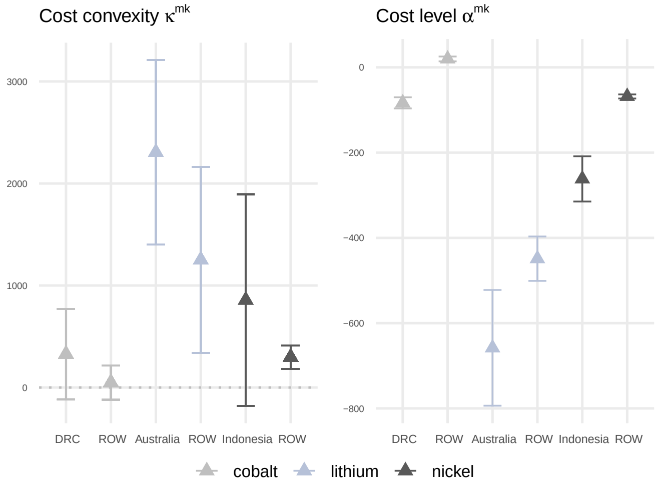
1. Cost convexity κ estimated from Euler equation (+ ε-inversion)

$$\underbrace{\Delta p^{mt} g^{it}}_{\Delta mr^{it}} - \Delta ac^{it} = \underbrace{\frac{\kappa}{2}\Delta x^{it}}_{\Delta \widetilde{mc}^{it}(x^{it}) - \Delta \widetilde{ac}^{it}(x^{it})} + \eta^{it}$$

2. Cost level α recovered from ac data (+ κ-correction)

$$ac^{it} - \frac{\kappa}{2}x^{it} = \alpha + \varepsilon^{it}$$

Results: Cost parameter heterogeneity

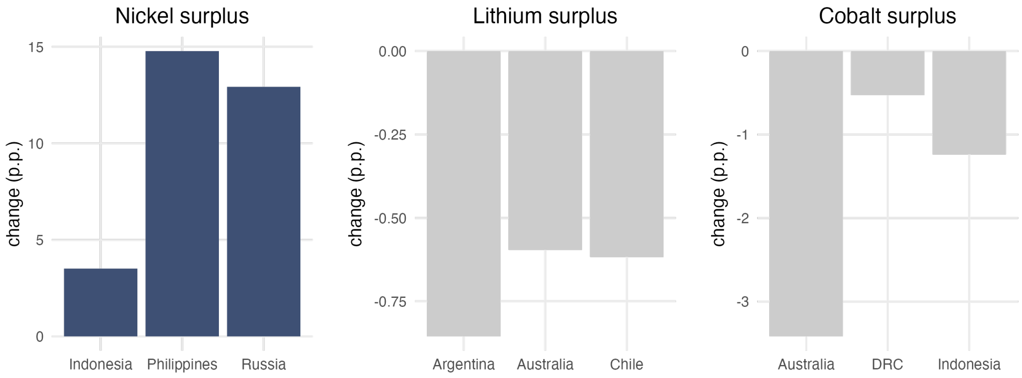


Top producers have:

- lower cost level α
  - reflects lower observed average costs
- higher cost convexity κ
  - mc rise faster as $x \uparrow$ (e.g., fixed factors)

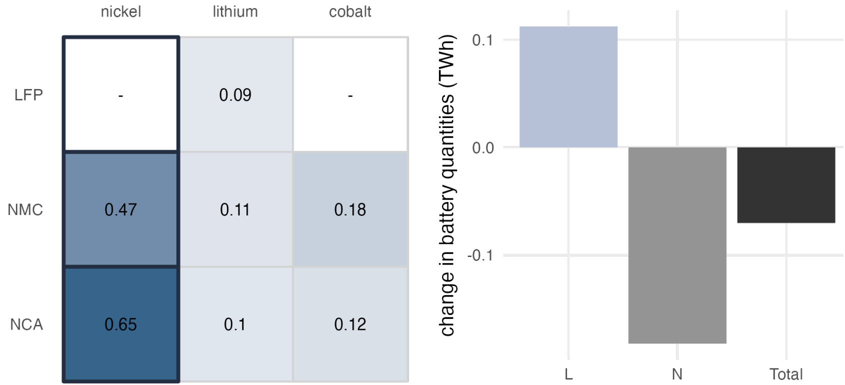
Outline

1. Indonesian nickel supply cut: upstream spillovers



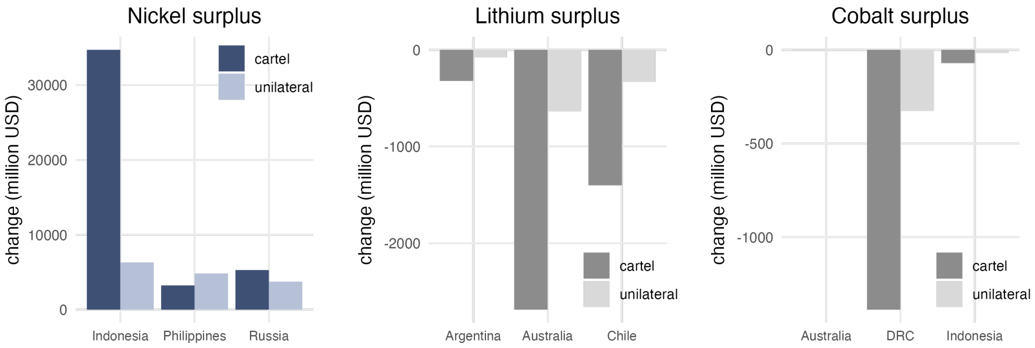
- Substitutes win (other Ni producers free-ride) and complements lose (Li/Co)
  - Distinct from single resource analyses (e.g., OPEC)

1. Indonesian nickel supply cut: downstream adoption



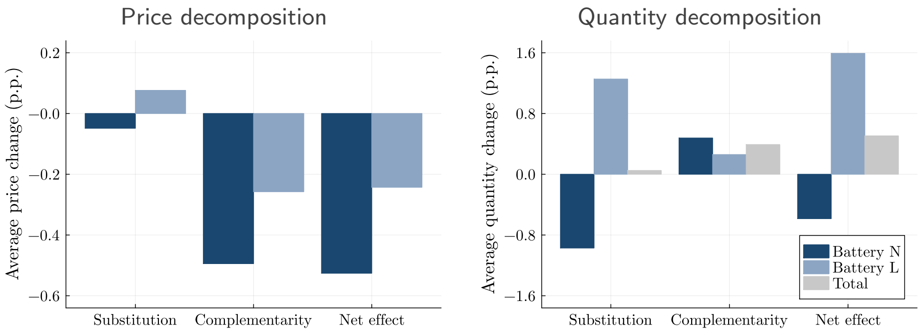
- Aggregate adoption falls, but with dampening from battery switching

2. Within-mineral consolidation (nickel cartel)



- Consolidation is anti-competitive and anti-adoption $(p \uparrow q \downarrow)$
  - Cartel delivers larger cut and spillovers than unilateral Indonesian cut

3. Across-mineral consolidation (multi-mineral merger)



- Consolidation can be pro-competitive and pro-adoption ($p \downarrow q \uparrow$)
  - Pre-merger prices too high because of complementarity (double marginalization)
  - Complements/substitutes analogous to vertical/horizontal mergers (Cournot, 1838)

Consolidation in practice

- A “multi-mineral cartel” is an analogy for common ownership across minerals
- In practice, consolidation happens via multinationals buying out mines

Bloomberg

Tianqi Expands Lithium Empire With Deal to Buy Australian Miner

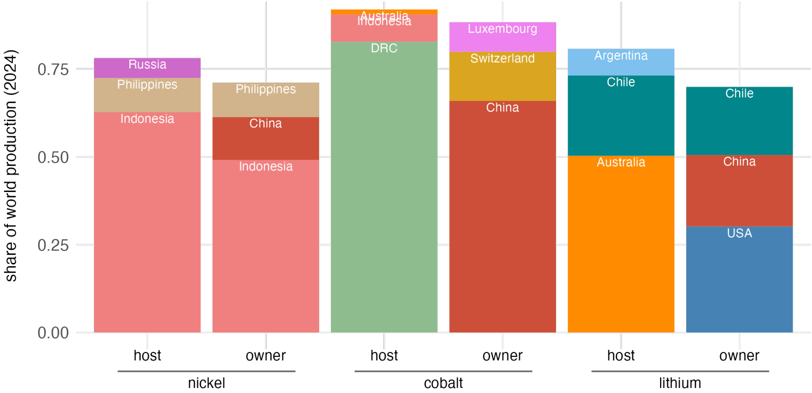
Industry News

Chinese firms control around 75 percent of Indonesian nickel capacity, report finds

Reuters

China Moly buys 95% of DRC copper-cobalt mine from Freeport for $550 million

Common ownership across mineral markets



- China is only country with significant ownership **across** minerals
  - Salient short-term costs (geopolitically-motivated supply restrictions)
  - Less acknowledged long-term benefits (lower avg prices, more green adoption)

Conclusion

- Critical minerals will power the green transition
    - Under-studied industry relative to current policy interest
- Mineral resources are **concentrated** and **interdependent**
    - Complementarity flips implications for geopolitics and green adoption