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, but traded globally

- What are the global impacts of national mineral policy?

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

- Concentrated endowments give countries market power
  - But exercising market power may induce switching
- Geopolitics
  - Mineral policy affects all mineral-endowed countries
- Green adoption
  - Mineral policy 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

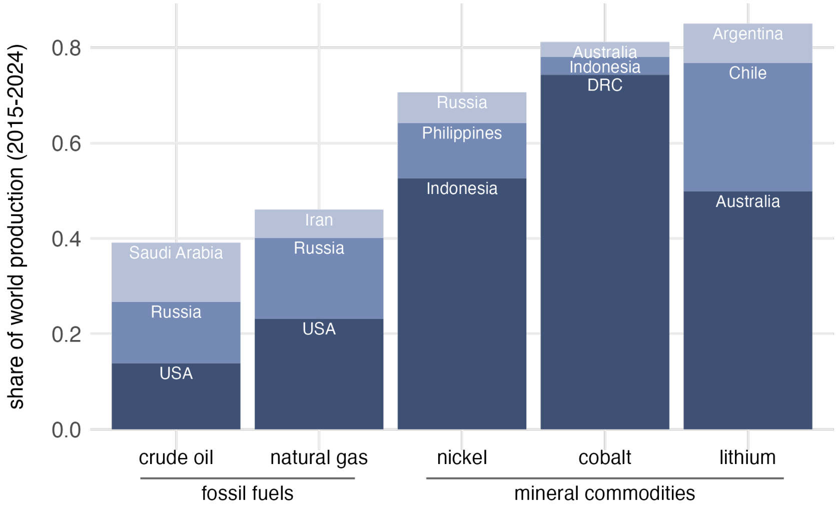
- Energy technology inputs with supply disruption risk (Energy Act of 2020)
  - Separate: rare earths for national security purposes

	EV battery market		
	Lithium	Cobalt	Nickel
%	65	45	11
$1B	18	7	5

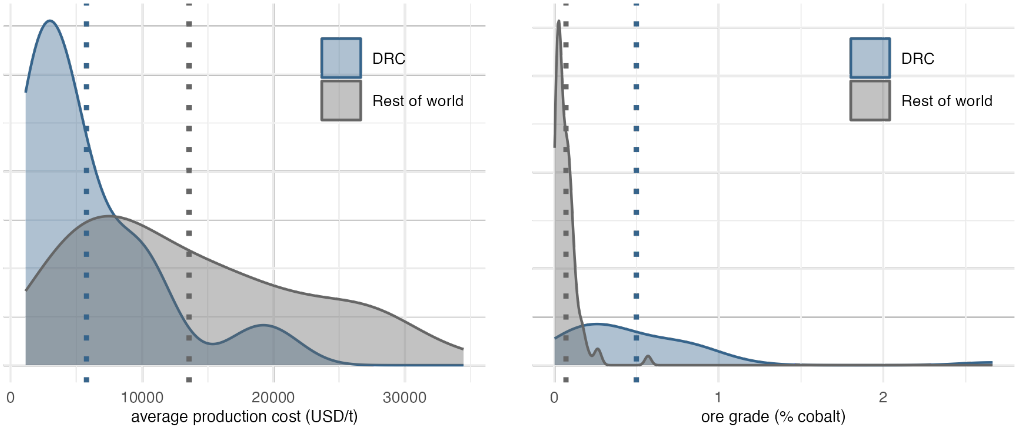
Data

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

Mineral supply is geographically concentrated

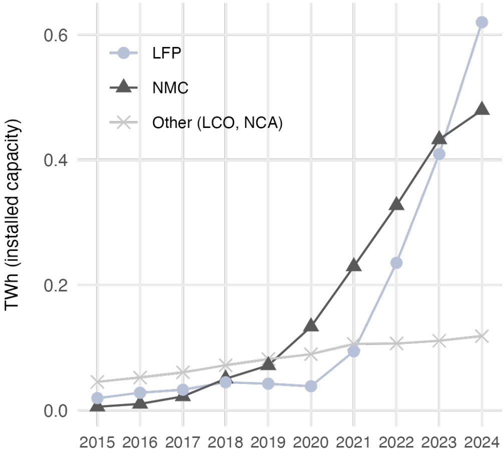


With heterogeneous costs across mines



Mineral recipes vary by battery technology

	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

1. **Technology demand** d_j with scientific recipes r_j^m
2. **Mineral supply** s^m with dynamics and heterogeneous endowments
3. **Equilibrium prices** (p^m, p_j) with heterogeneous policies

Demand

Demand by technology j, region k, year t

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

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

- Almost ideal demand system (Deaton & Muellbauer 1980)
  - Expenditure shares w_{jkt}, prices p_{jt}, translog price index P_t

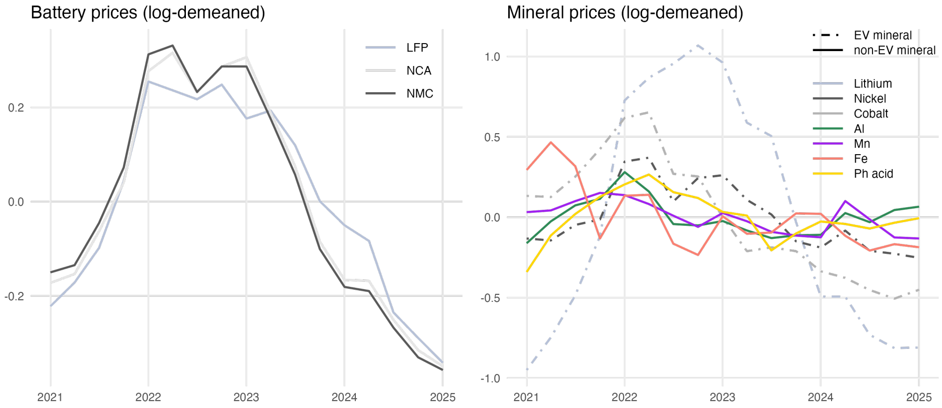
- Flexible substitution across differentiated technologies
- **Endogeneity** from demand shocks ε_{jkt}

Estimation with instruments

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

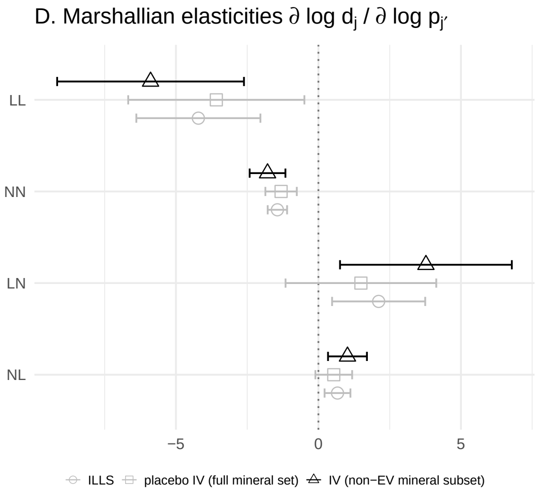
- Secondary mineral prices as cost shifters for technology prices
  - Relevance: minerals affect technologies through recipes r_j^m
  - Exclusion: EVs are less than 3% of demand for $\mathcal{M}'$

Price variation



- Recipe variation disentangles technology prices, which move together
  - We exclude lithium, cobalt, and nickel, which move with technology

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

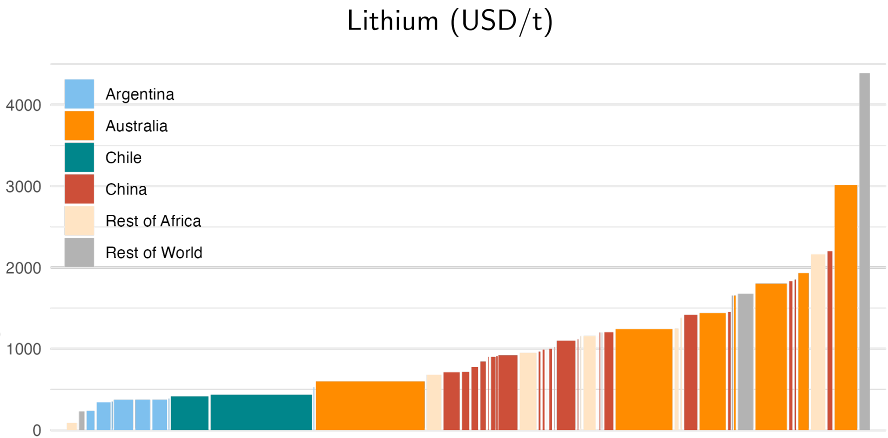
Supply by mine i, year t

- We can construct supply curves directly from our cost data
  - Usually no cost data, so need to estimate full cost structure

- Simplest model assumes myopia, $mc = ac$, price-taking
  - Need marginal revenue mr^{it}, marginal cost mc^{it}
  - Have capacity $\bar{s}^i$, prices p^t, average cost ac^{it} as data

$$s^{it} = \bar{s}^i \cdot \overbrace{\mathbb{1}(\underbrace{mr^{it}}_{p^t} > \underbrace{mc^{it}}_{ac^{it}})}^{\text{myopia}}$$

Average costs by mine



Challenges

- With myopia, no **dynamics** from finite reserves
- With $mc = ac$, no **cost convexity**
  - Local approximation only for small changes
  - Predicts all-or-nothing production and discrete jumps
- We keep price-taking by mines (with market power by country)

Dynamics with cost convexity

Euler condition	Average cost	Marginal cost
$p^t g^i - mc^{it} = \beta \mathbb{E}^{it}[p^{t+1} g^i - mc^{it+1}]$	$ac^{it} = \frac{\kappa}{2} u^{it} + \varepsilon^{it}$	$mc^{it} = \kappa u^{it} + \varepsilon^{it}$

- Extraction x^{it} and ore grade g^i yield production $s^{it} = x^{it} g^i$
  - Shadow cost of extraction for finite reserves (Hotelling)
  - Cost convexity κ in capacity utilization $u^{it} = x^{it} / \bar{x}^i$
  - Unobserved costs ε^{it} enter linearly
- Estimate convexity κ with **endogeneity** from cost shocks ε^{it}

Differencing

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

$$\underbrace{\Delta p^t g^i}_{\beta y^{it+1} - y^{it}} = \kappa \Delta u^{it} + \Delta \varepsilon^{it} + \underbrace{\eta^{it}}_{\beta y^{it+1} - \beta \mathbb{E}^{it}[y^{it+1}]}$$

- **Average costs** in differences

$$\Delta ac^{it} = \frac{\kappa}{2} \Delta u^{it} + \Delta \varepsilon^{it}$$

- We subtract to eliminate $\Delta \varepsilon^{it}$

$$\Delta p^t g^i - \Delta ac^{it} = \frac{\kappa}{2} \Delta u^{it} + \eta^{it}$$

Estimation with instruments

1. Estimate convexity κ with instrument $u^{it} \in \mathcal{J}^{it}$ (Hall 1978)

$$\Delta p^t g^i - \Delta ac^{it} = \frac{\kappa}{2} \Delta u^{it} + \eta^{it}$$

2. Recover unobserved costs ε^{it}

$$ac^{it} - \frac{\hat{\kappa}}{2} u^{it} = \hat{\varepsilon}^{it}$$

Supply curves

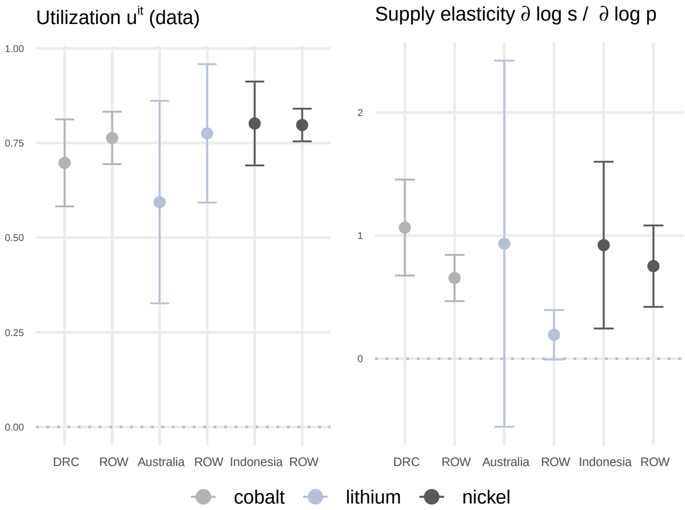
$$u^{it} = \frac{2}{\kappa}(p^t g^i - ac^{it} - \bar{\eta}^{it}), \quad \frac{\partial \log s^{it}}{\partial \log p^t} = \frac{p^t g^i}{p^t g^i - ac^{it} - \bar{\eta}^{it}}$$

- Still reflect cost data ac^{it}
  - But with convexity through κ
  - Dynamics through $\bar{\eta}^{it} = \sum_{t'=t}^{\infty} \beta^{t'-t} \eta^{it'}(p^{t'+1})$

Additional features

- Richer heterogeneity in costs
  - Beyond observed $(g^i, \bar{x}^i)$ and common κ
- Ore grade that evolves with extraction
  - Production today affects revenues tomorrow
- 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

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})

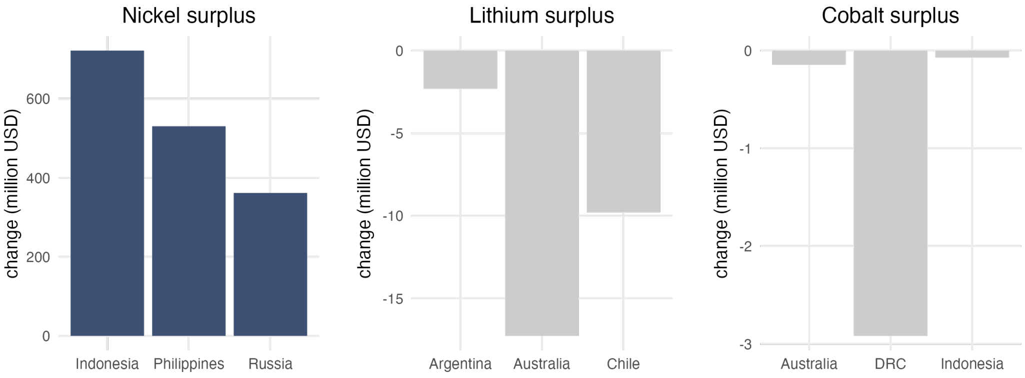
$$p_{jt} = \sum_m r_j^m p^{mt} + \mu_{jt}$$

1. Supply chain vulnerability

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

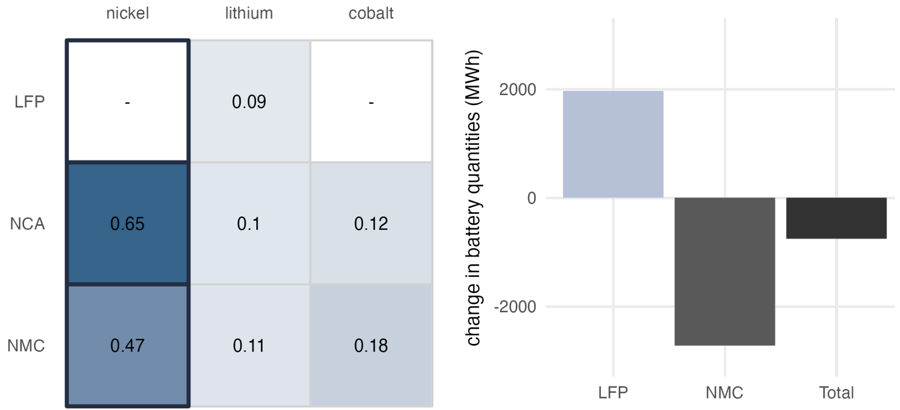
- Remove top producer, solve for equilibrium price changes
  - Bigger for lithium: inelastic supply from competitors
  - Biggest for cobalt: DRC has major ore grade advantage

2. Unilateral policy: Indonesian nickel and geopolitics



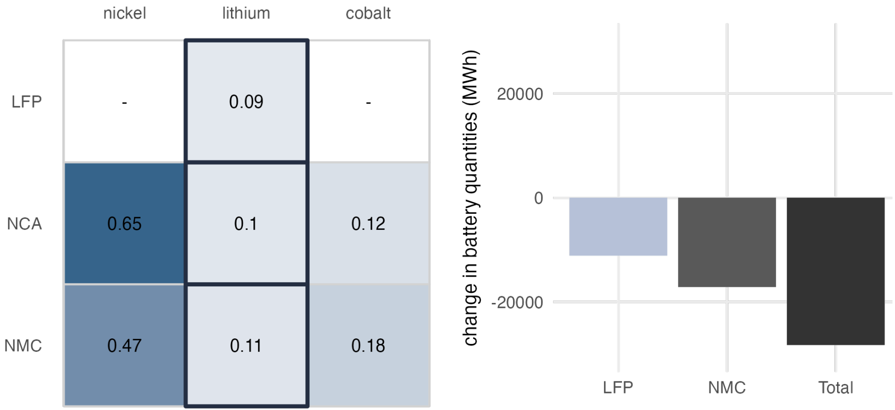
- Indonesia restricts nickel: substitutes win and free-ride, complements lose

2. Unilateral policy: Indonesian nickel and green adoption



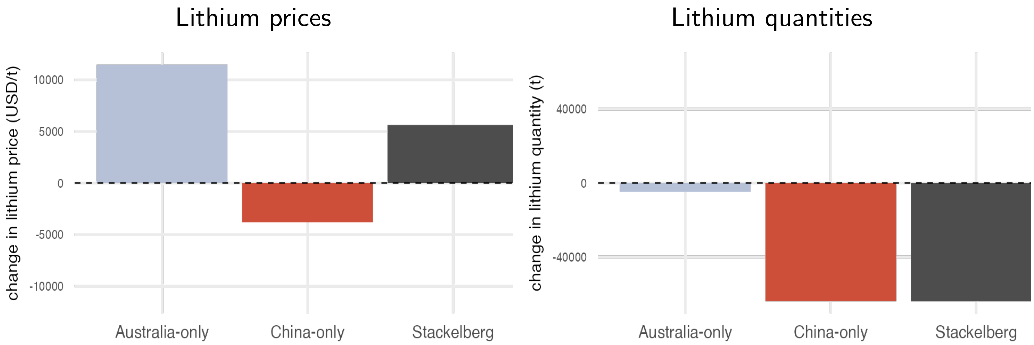
- Aggregate adoption falls, but with dampening from switching

3. Unilateral policy: Australian lithium and green adoption



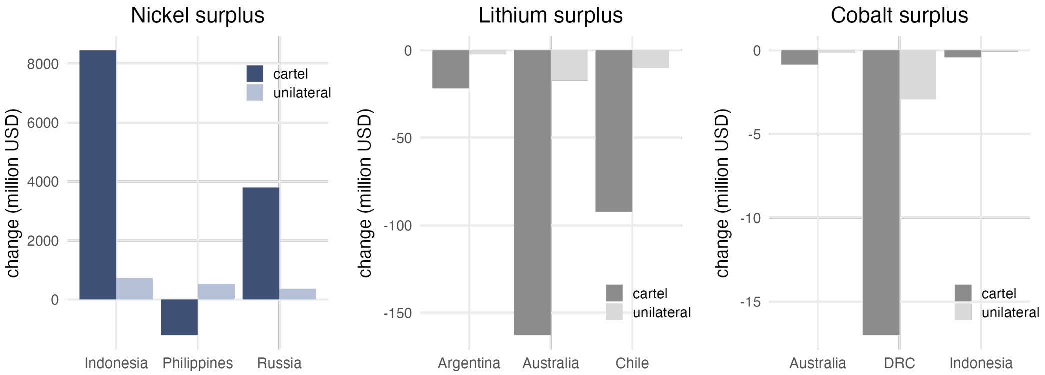
- Aggregate adoption falls greatly, as lithium is a universal input

4. Bilateral policy: Australian lithium and Chinese retaliation



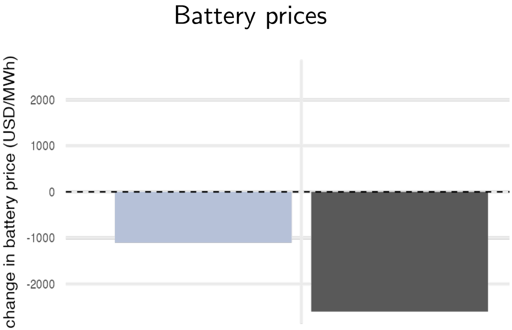
- China restricts lithium demand: prices rise less, quantities fall much more

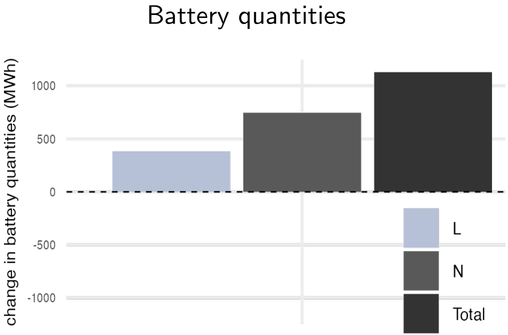
5. Cartel policy: OPEC for nickel (ONEC)



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

6. Cartel policy: OPEC for nickel and lithium





- Nickel and lithium cartels merge: prices fall, adoption rises
  - Complementarity leads to pro-competitive effects (Cournot 1838)
  - Potential gains from common ownership by Chinese firms

Summary

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