Critical Minerals, Geopolitics, and the Green Transition

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Critical minerals will fuel the green transition

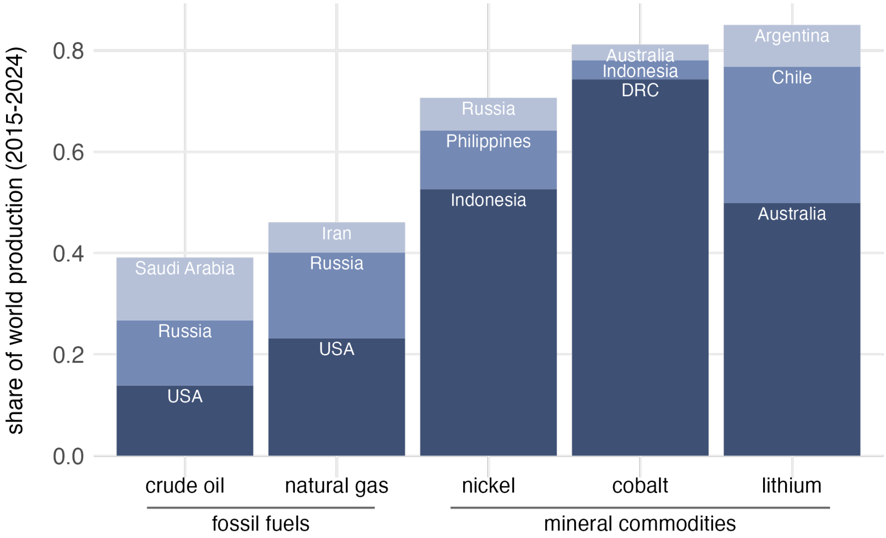
- Lithium, nickel, cobalt, and other minerals
  - Critical for producing advanced batteries
  - Geographic concentration, global trade, and active policy intervention

- What are the global impacts of industrial policy for minerals?
  - Highlighting **policy spillover** effects
  - With implications for geopolitics and green adoption

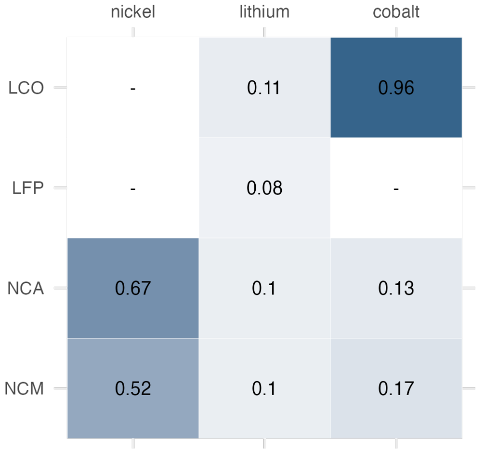
Data

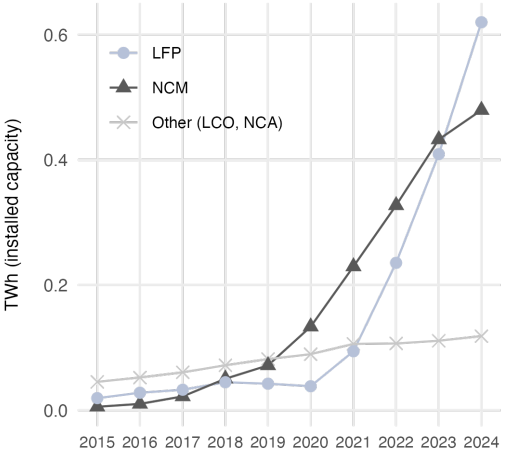
- Annual, mine-level mineral production (GlobalData, Benchmark Minerals)
  - Capacity, ore grade, ownership structure, mine type, mining method
- Annual, global (or continent-level) battery consumption (Benchmark Minerals)
  - By battery chemistry
- Annual prices + battery-mineral "recipes"
  - Battery prices (ICCSINO)
  - Mineral prices (Trading Economics)

Critical minerals are geographically concentrated

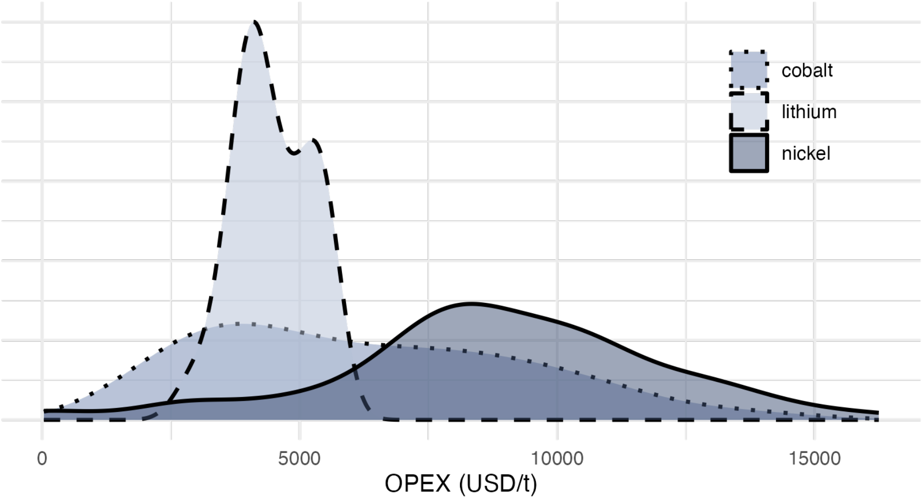


Critical minerals power advanced batteries





Mines have heterogeneous costs



Theory

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

Policy spillovers

- Own-price demand elasticity
  - Higher $p^\ell \rightarrow$ lower d^ℓ
  - Partly offset by substitution to technology N, which still uses ℓ

- Cross-price demand elasticity
  - Higher $p^n \rightarrow$ lower d^ℓ or higher d^ℓ
  - **Complements**: lower d^ℓ from joint use in technologies L and N
  - **Substitutes**: higher d^ℓ from shift to technology L, which uses more ℓ

- On net, lithium and nickel can be gross complements or substitutes

Geopolitics and green adoption

- Consider country ℓ, which sets policy τ^ℓ that restricts s^ℓ
- Geopolitics
  - Own-policy effect: lower s^ℓ, higher p^ℓ
  - Cross-policy effect if **complements**: lower p^n
  - Cross-policy effect if **substitutes**: higher p^n
- Green adoption
  - **Complements**: higher or lower $d_L + d_N$ (higher p^ℓ but lower p^n)
  - **Substitutes**: unambiguously lower $d_L + d_N$ (higher p^ℓ and higher p^n)

Empirical model

1. **Demand** d_j for technologies
2. **Supply** s^m of minerals
3. **Equilibrium prices** (p^m, p_j)

Demand by technology j, year t

- Almost ideal demand system with expenditure shares w at prices p

$$w_{jt} = \alpha_{jt} + \beta_j \log \frac{x_t}{P_t} + \sum_{\hat{j}} \gamma_{j\hat{j}} \ln p_{\hat{j}t}$$

$$P_t = \sum_j \alpha_{jt} \ln p_{jt} + \frac{1}{2} \sum_{j,\hat{j}} \gamma_{j\hat{j}} \ln p_{jt} \ln p_{\hat{j}t}$$

- **Estimation:** iterative linear least-squares
  - Instrumenting for prices with supply shocks

Supply by mineral $m(i)$, mine i, year t

- Ore extraction s for ore grade γ, crude extraction S

$$s^{it} = \gamma^{it} S^{it}$$

- Quadratic crude costs, linear ore revenues (as price takers),

$$c^{it} = a^i + b^m \frac{S^{it}}{k^i} + \varepsilon^{it}, \quad r^{it} = p^{mt} \gamma^{it}$$

- **Estimation:** linear FOC with fixed effects (μ^i, μ^{mt}), mine-level variation γ^{it}

$$\frac{S^{it}}{k^i} = \frac{p^{mt}\gamma^{it}}{b^m} - \frac{a^i}{b^m} - \frac{\varepsilon^{it}}{b^m}$$

Equilibrium prices

- Technologies derive from minerals according to **recipes** R_j^m
- Mineral prices clear mineral markets

$$d^{mt} = \sum_j R_j^m d_{jt} + o^{mt}, \quad s^{mt} = \sum_{i \in I^{mt}} s^{it}$$

- Technology prices follow from mineral prices

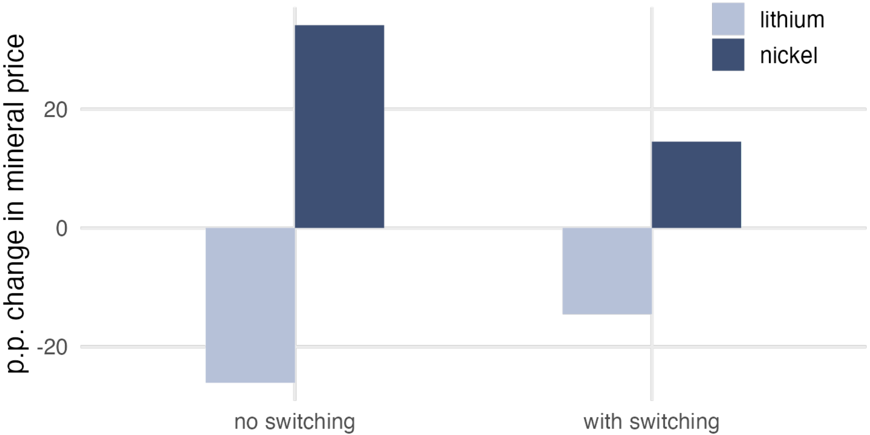
$$p_{jt} = \sum_m R_j^m p^{mt} + \eta_{jt}$$

Counterfactuals

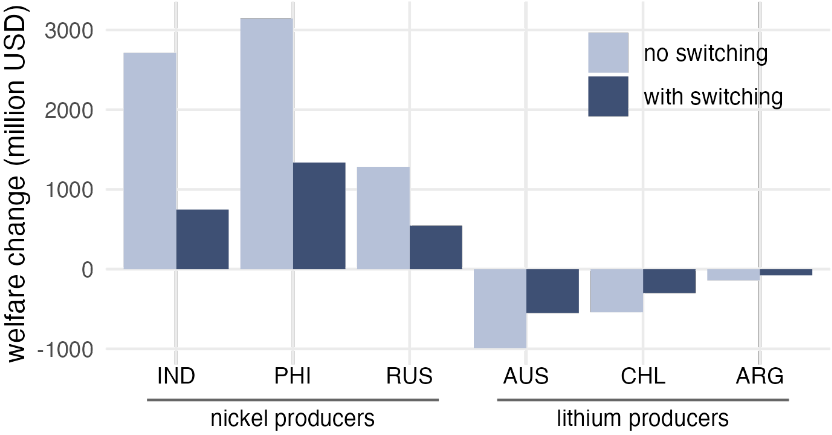
- **Indonesian nickel policy** and Australian lithium policy
  - Impose optimal tax policy τ^m, solve for equilibrium (p^m, s^m)
  - Evaluate geopolitics and green adoption

- Decompose policy spillovers
  - With tech switching: complementarity $+$ substitution
  - No tech switching: only complementarity

Price effects of Indonesian nickel policy

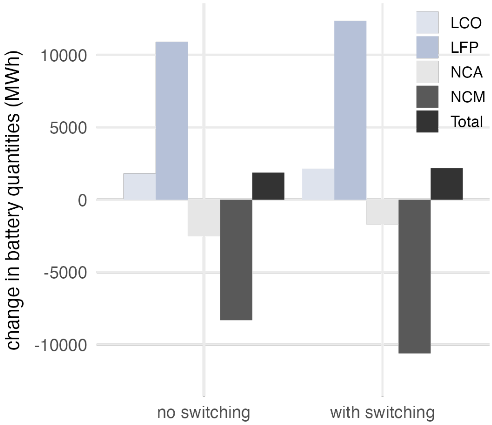


Geopolitics under Indonesian nickel policy



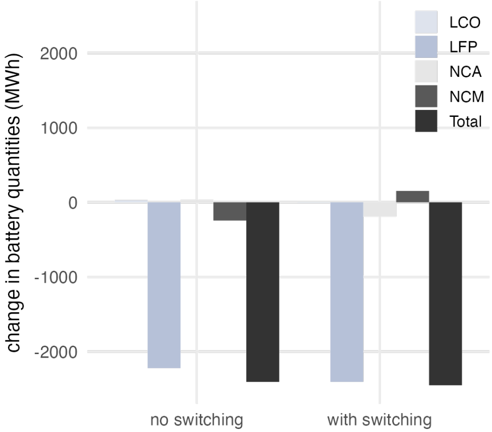
Green adoption under Indonesian nickel policy

	nickel	lithium	cobalt
LCO	-	0.11	0.96
LFP	-	0.08	-
NCA	0.67	0.1	0.13
NCM	0.52	0.1	0.17



Green adoption under Australian lithium policy

	nickel	lithium	cobalt
LCO	-	0.11	0.96
LFP	-	0.08	-
NCA	0.67	0.1	0.13
NCM	0.52	0.1	0.17



Summary

- Critical minerals will fuel the green transition
- Industrial policy has **policy spillovers**
  - With implications for geopolitics and green adoption