Critical Minerals, Geopolitics, and the Green Transition

Domínguez-Iino, Elliott & Hsiao (2026)

Hung D. Hoang
KU Leuven

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The green transition creates a new concentration problem

Main question

How does concentrated control of lithium, nickel, and cobalt affect

mineral prices, battery substitution, green adoption, producer welfare?

Central mechanism

- Batteries substitute across technologies.
- Minerals are jointly used within technologies.
- Dynamic fringe supply determines strategic leverage.

Methodology

- A global dynamic equilibrium model capturing upstream and downstream elements
- Four sets of counterfactuals: supply chain vulnerability, unilateral mineral policy, mineral cartels, market power of Chinese multinationals

Literature I: trade, environment, and geoeconomics

Trade and the environment

- Rauscher (1997)
- Copeland and Taylor (2003)
- Kortum and Weisbach (2017, 2024)
- Copeland, Shapiro, and Taylor (2022)
- Hsiao (2026)

Geoeconomics

- Hirschman (1945)
- Blackwill and Harris (2016)
- Mohr and Trebesch (2025)
- Clayton, Maggiori, and Schreger (2026a,b)

Contribution

(One of) the first paper that brings geoeconomic coercion into an environmental setting.

Literature II: natural resources, market power, and electric vehicles (EVs)

Market power of natural resources

- Aguirregabiria and Luengo (2016)
- Asker, Collard-Wexler, and De Loecker (2019)
- Asker et al. (2024); Kellogg (2024)
- De Cannière (2025)

Electric vehicles

- Barwick et al. (2025, 2026)
- Kwon (2025); Allcott et al. (2026)
- Head et al. (2026); Remmy (2026)

Contribution

DEH links **multiple upstream minerals** to downstream battery substitution. Resource models usually study one commodity; EV studies emphasize downstream demand.

A global panel dataset at the mine level (2010 - 2024)

Battery demand

EV sales data (BMI, 2025): Battery installations by chemistry, make, model, country, and quarter.

Engineering recipes

$$r_j^m = \frac{\text{kg of mineral } m}{\text{kWh of battery } j}.$$

Argonne National Laboratory (Knehr et al., 2024)

Mine supply

397 mines (GlobalData, 2025; S&P Global, 2025): production, capacity, ore grade, reserves, cost, and ownership.

Coverage of world production

92% lithium **94% cobalt** **80% nickel**

The model is detailed upstream and downstream, but parsimonious midstream

Mining — costs, capacity, reserves → **Refining** — compressed into wedge → **Battery making** — recipes and substitution → **EV production** — expenditure exogenous

Upstream and downstream are explicitly modeled

- Mine extraction and intertemporal scarcity
- Battery technologies and mineral recipes
- Substitution across batteries

Midstream is underdeveloped

$$\mu_{jt} = \text{refining} + \text{manufacturing} + \text{markups}.$$

Fact (1): Lithium, nickel, and cobalt enter through different margins

Mineral	EV use	Role
Lithium	LFP, NMC, NCA	Common input
Nickel	NMC, NCA	Enables substitution toward LFP
Cobalt	NMC, NCA	Concentrated complementary input

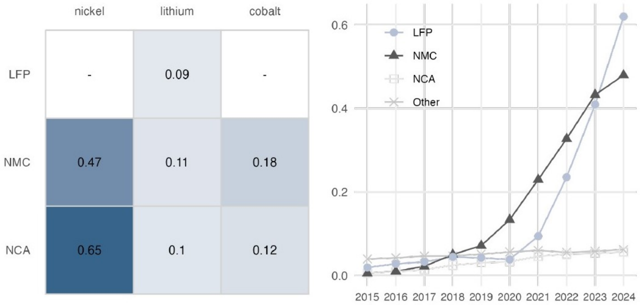
EV share: Li 65%, Co 45%, Ni 11%.

Battery storage adds further lithium and cobalt demand.

Fact (2): Battery chemistry creates substitution and complementarity simultaneously

Figure 3: Battery technologies

(a) Battery recipes (kg/kWh) (b) Global adoption (TWh)



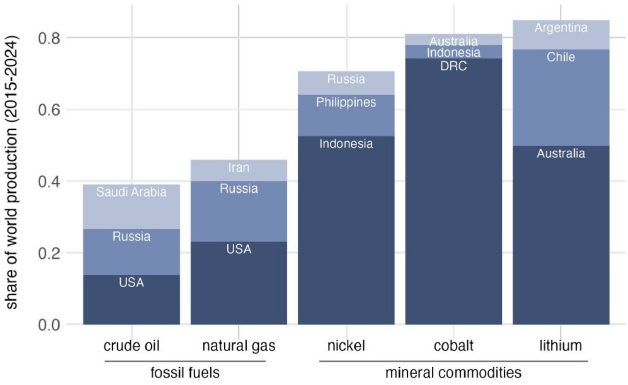
- LFP uses lithium but no nickel or cobalt.
- NMC/NCA use all three jointly.
- LFP's global share rose from about 5% to 60%, 2020 - 2024.

Key distinction

Technologies are **substitutes**; minerals within a technology are **complements**.

Fact (3): Critical mineral production is unusually concentrated

Figure 1: Market concentration in world production (2015-2024)



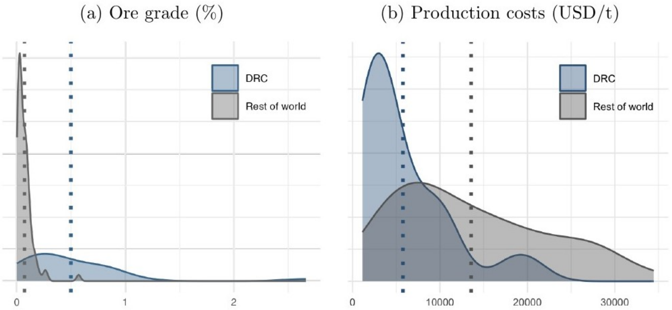
- Fossil-fuel top-3 shares: roughly **40–50%**.
- Lithium, nickel, cobalt: roughly **70–85%**.
- The same pattern holds for reserves.

Takeaway

Geology makes concentration intrinsic, *but concentration alone does not determine market power*.

Fact (4): The DR Congo's cobalt advantage is geological and costly to replace

Figure 2: Cobalt production across mines



- Average DRC cobalt grade is about **5 times** that elsewhere.
- Higher grade translates into substantially lower production cost.
- Removing DRC output moves replacement supply far up the cost curve.

A simple model isolates the mechanism

Minerals and technologies

$$m \in \{\ell, n\} = \{\text{lithium}, \text{nickel}\},$$

$$j \in \{L, N\} = \{\text{LFP}, \text{NMC/NCA}\}.$$

Recipe matrix

$$R = \begin{pmatrix} r_L^\ell & 0 \\ r_N^\ell & r_N^n \end{pmatrix}.$$

Interpretation

- $r_N^\ell > 0$: lithium and nickel are jointly used in N.
- Lithium is common to L and N; nickel is specific to N.

An increase in nickel price generates 2 opposing effects on lithium demand

Lithium demand: $d^\ell = d_L r_L^\ell + d_N r_N^\ell$, Nickel demand: $d^n = d_N r_N^n$.

$$\text{Cross-price effect: } \frac{\partial d^\ell}{\partial p^n} = \underbrace{\delta_{LN} r_L^\ell r_N^n}_{\text{substitution if } >0} + \underbrace{\delta_{NN} r_N^\ell r_N^n}_{\text{complementarity if } <0}$$

Gross substitutes

$\frac{\partial d^\ell}{\partial p^n} > 0$ if substitution effect dominates

Gross complements

$\frac{\partial d^\ell}{\partial p^n} < 0$ if complementarity effect dominates

Proposition 1: Mineral policy creates allies or rivals

Restrictive nickel policy

Country n restricts nickel supply, $\tau^n \uparrow$, implying

$$\frac{dp^n}{d\tau^n} > 0, \qquad \text{sign}\left(\frac{dp^\ell}{d\tau^n}\right) = \text{sign}\left(\frac{\partial d^\ell}{\partial p^n}\right).$$

Gross substitutes

$$\frac{\partial d^\ell}{\partial p^n} > 0 \quad \Longrightarrow \quad p^\ell \uparrow$$

Lithium producers gain producer surplus and **free-ride** on the nickel restriction.

Producer interests are aligned.

Gross complements

$$\frac{\partial d^\ell}{\partial p^n} < 0 \quad \Longrightarrow \quad p^\ell \downarrow$$

Lithium producers lose producer surplus because nickel policy depresses lithium demand.

Producer interests are in conflict.

Proposition 2: Nickel policy opens an escape route

Benchmark: no joint use

$$r_N^\ell = 0 \quad \Longrightarrow \quad p_L \uparrow,\ p_N \uparrow \quad \Longrightarrow \quad d_L + d_N \downarrow .$$

With joint use and **gross complementarity**,

$$\tau^n \uparrow \Longrightarrow p^n \uparrow \Longrightarrow d_N \downarrow \Longrightarrow p^\ell \downarrow .$$

Hence battery L becomes cheaper:

$$\frac{dp_L}{d\tau^n} = r_L^\ell \frac{dp^\ell}{d\tau^n} < 0.$$

Green transition implication

Consumers substitute toward L: the indirect subsidy to L **offsets part of the decline in total adoption**.

Proposition 3: Lithium policy closes the escape route

Benchmark: no joint use

$$r_N^\ell = 0 \implies p_L \uparrow,\ p_N \uparrow \implies d_L + d_N \downarrow.$$

With joint use, lithium is an input into **both** batteries:

$$p_L = p^\ell r_L^\ell, \qquad p_N = p^\ell r_N^\ell + p^n r_N^n.$$

Restrictive lithium policy therefore adds a direct tax on N:

$$\underbrace{r_N^\ell \frac{dp^\ell}{d\tau^\ell}}_{>0 \text{ only with joint use}} \subset \frac{dp_N}{d\tau^\ell}.$$

Green transition implication

Switching from L to N no longer avoids lithium: joint use **deepens the decline in total adoption**.

Battery demand: Almost Ideal Demand System (Deaton & Muellbauer, 1980)

- For technology j, region k, and period t, DEH specifies demand in product space with expenditure share w_{jkt} given by

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

α_{jt} : technology quality, β_j : expenditure effect, $\gamma_{jj'}$: price response.

- Quantity demanded follows from the battery-price vector $\mathbf{p}_t = \{p_{jt}\}_{j \in \mathbb{J}}$:

$$d_{jkt} = \frac{X_{kt} w_{jkt}}{p_{jt}}$$

Demand restrictions map parameters into elasticities

Adding up, homogeneity, and symmetry

$$\sum_j \alpha_{jt} = 1, \qquad \sum_j \beta_j = 0, \qquad \sum_j \gamma_{jj'} = 0, \qquad \sum_{j'} \gamma_{jj'} = 0, \qquad \gamma_{jj'} = \gamma_{j'j}.$$

Marshallian price elasticity

$$\epsilon_{jj'} = \frac{\gamma_{jj'} - \beta_j \bar{w}_{j'}}{\bar{w}_j} - \mathbf{1}\{j = j'\}$$

where $\bar{w}_j$ is the worldwide expenditure share averaged over time for battery j

Iterated linear least squares (Blundell & Robin, 1999) handles the translog price index

The exact price index P_t contains unknown demand parameters, making the system nonlinear.

1. Initialize P_t with the Stone price index.
2. Estimate the share equation conditional on P_t.
3. Recompute P_t using the estimated translog index.
4. Iterate until the parameter vector converges.

Why ILLS is convenient

Conditional on P_t, the AIDS system is linear in the parameters.

Price endogeneity: Non-EV mineral costs instrument for battery prices

Battery prices are endogenous: $E[p_{jt}\varepsilon_{jkt}] \neq 0$. Construct

$$z_{jt} = \sum_{m \in \mathcal{M}'} r_j^m p_{mt}, \qquad \mathcal{M}' = \{\text{aluminum, phosphoric acid, iron, manganese}\}.$$

Relevance

These minerals enter the engineering recipes and therefore shift predicted battery cost.

Exclusion restrictions

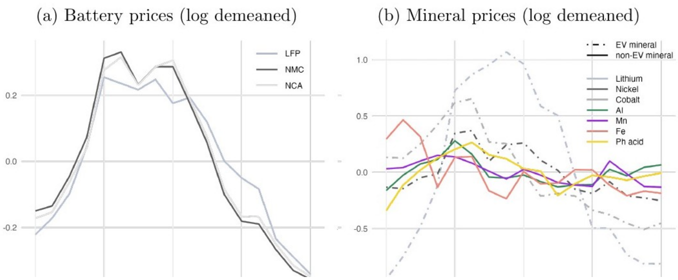
EV batteries account for less than 3% of their global demand, so battery-demand shocks are unlikely to move their prices.

Deliberate exclusion

Lithium, nickel, and cobalt are omitted because EV demand materially affects their prices.

Price data show why recipe-based instruments are necessary

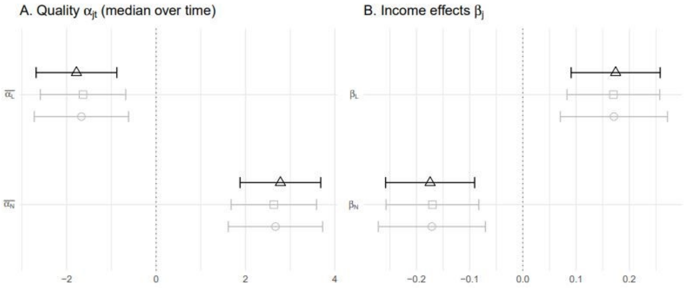
Figure 4: Battery and mineral prices



- LFP and NMC/NCA prices move closely together.
- EV-intensive minerals co-move more strongly with battery prices.
- Recipes turn common input-price changes into technology-specific predicted costs.

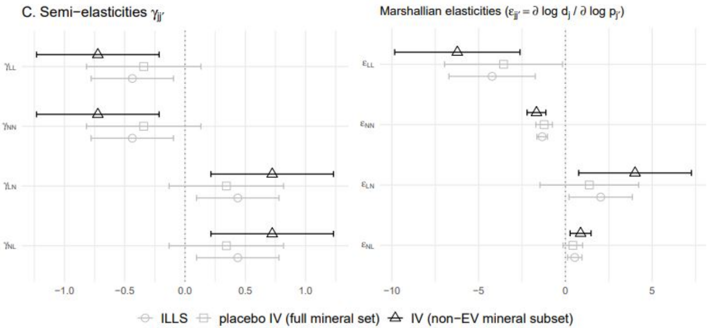
Demand estimates: Parameters

Figure 5: Demand estimates



- LFP has lower estimated quality.
- Rising expenditure shifts shares toward LFP.

Demand estimates: Elasticities



- Own-price semi- and Marshallian elasticities are negative.
- Cross-price semi- and Marshallian elasticities are positive.
- Both technologies have elastic own-price demand, and LFP is especially price sensitive.

Model (1): Static

- Assumption: Large number of mines competing in the global markets $\rightarrow$ Mine-level price-taking
- Forward-looking mine i extracts ore x_{it}, with grade g_i, capacity $\bar{x}_i$, production s_{it}, and utilization u_{it}:

$$s_{it} = g_i x_{it}, \qquad u_{it} = \frac{x_{it}}{\bar{x}_i}.$$

- Convex cost:

$$C_{it} = \left(\alpha_i + \frac{1}{2}\kappa^m u_{it} + \varepsilon_{it} \right) x_{it}.$$

Hence

$$ac_{it} = \alpha_i + \frac{1}{2}\kappa^m u_{it} + \varepsilon_{it}, \qquad mc_{it} = \alpha_i + \kappa^m u_{it} + \varepsilon_{it}.$$

Model (2): Dynamics with finite reserves

- Mines extract from finite reserves with a stock R_{it}

$$R_{i,t+1} = R_{it} - x_{it}$$

- The Euler condition (Hotelling, 1931):

$$mr_{it} - mc_{it} = \beta E_{it}[mr_{i,t+1} - mc_{i,t+1}] \, .$$

Scarcity rent

$$\lambda_{it} \equiv mr_{it} - mc_{it}$$

is the value of leaving one additional unit underground.

Consequence

Current extraction depends on the expected mineral-price path, not only today's price.

A conventional Euler regression has two endogeneity problems

Quasi-differencing gives

$$\Delta p_{mt} g_i = \Delta \alpha_i + \kappa^m \Delta u_{it} + \Delta \tau_{km} g_i + \Delta \tau_{om} g_i + \Delta \varepsilon_{it} + \eta_{it}.$$

1. Unobserved cost shocks

A positive cost shock reduces utilization:

$$\mathrm{Cov}(\Delta u_{it}, \Delta \varepsilon_{it}) < 0.$$

2. Expectational errors

By construction,

$$\mathrm{Cov}(\Delta u_{it}, \eta_{it}) < 0:$$

Δu_{it} rises with current utilization, while η_{it} falls with current utilization.

Both channels bias estimated cost convexity κ^m downward.

Solutions for endogeneity

- **Unobserved cost shocks:** Invert observed average cost:

$$\varepsilon_{it} = ac_{it} - \frac{1}{2}\kappa^m u_{it} - \alpha_i.$$

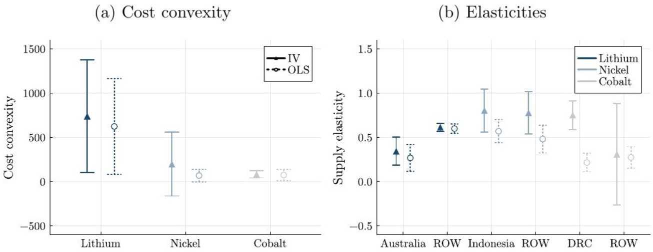
  Substitution into the Euler equation yields

$$\Delta p_{mt} g_i - \Delta ac_{it} = \frac{1}{2}\kappa^m \Delta u_{it} + \Delta\tau_{km} g_i + \Delta\tau_{om} g_i + \eta_{it}.$$

- **Expectational errors:** Instrument Δu_{it} with $u_{i,t-1}$. Lagged utilization is predetermined and orthogonal to η_{it} under rational expectations.

Estimates: Supply responses differ across minerals and countries

Figure 7: Supply estimates



- Lithium: Costs rise fast, but producers respond strongly to price signals
- Nickel: Moderate on both fronts
- Cobalt: Supply is rigid, making it vulnerable to shocks

A recovered midstream wedge links upstream mining and downstream EV manufacturing

$$p_{jt} = \sum_{m \in \mathcal{M}} r_j^m p_{mt} + \mu_{jt}.$$

Recovered wedge μ_{jt}

- mineral refining costs;
- battery manufacturing costs;
- potential midstream markups.

Counterfactual assumption

$$\mu_{jt}^{CF} = \mu_{jt}^{2024}.$$

Mineral-price changes pass through, but midstream costs and markups remain fixed.

Dynamic equilibrium clears every mineral market along the entire price path

$$s_{mt}(p_{mt}, p_{m,t+1}, \ldots, p_{mT}) = \sum_j r_j^m d_{jt}(\boldsymbol{p}_t) + \nu_{mt}, \qquad t = 2024, \ldots, 2035.$$

1. Guess mineral-price paths $\{\mathbf{p}_t\}_{t=2024}^{T}$
2. Solve each mine's extraction path backward, taking the guessed price path as given.
3. Compute battery demand and non-EV mineral demand.
4. Update prices until every mineral market clears in every year.

Baseline equilibrium: Maintained assumptions for 2024–2035

Demand and technology

- Regional battery expenditure follows BMI forecasts.
- Non-EV mineral demand has elasticity -0.10.
- Battery recipes and the 2024 midstream wedge are fixed.
- Demand shocks are set to zero.

Mining

- Planned mine openings enter exogenously.
- Reserve growth follows calibrated discovery rates.
- Mine-level cost and expectation shocks are set to zero.
- Terminal year is $T = 2035$.

What the counterfactuals identify

Changes relative to this baseline are generated by policy or supply disruptions, propagated through endogenous mineral and battery prices.

Policy objective: exercising upstream market power

A country or cartel C chooses production taxes $\boldsymbol{\tau}_C$ to maximize

$$W_C(\boldsymbol{\tau}_C) = \sum_{t=2024}^{2035} \beta^{t-2024} \left[PS_{C,t}(\boldsymbol{\tau}_C) + GR_{C,t}(\boldsymbol{\tau}_C)\right].$$

Unilateral policy

A producing country internalizes the effect of its supply restriction on its own producers and tax revenue.

Cartel policy

Members coordinate production taxes to maximize their collective upstream welfare.

Interpretation

The production tax implements an optimal restriction of mineral supply; all effects are measured relative to the no-policy baseline.

Counterfactuals (1): Supply chain disruptions

Table 2: Supply disruptions

	Price effects (%)				
	Lithium	Nickel	Cobalt	Battery L	Battery N
Lithium (Australia)	107	−1.09	−3.69	9.47	9.46
Nickel (Indonesia)	−1.84	76.0	−3.43	−0.17	3.55
Cobalt (DRC)	−6.19	−3.74	865	−0.58	14.1

Removing a dominant producer reveals gross complementarity

- Own-price effects: Australia Li $+107\%$, Indonesia Ni $+76\%$, DRC Co $+865\%$.
- Other mineral prices fall in every disruption.
- Battery-price effects are smaller because minerals are only part of total cost.

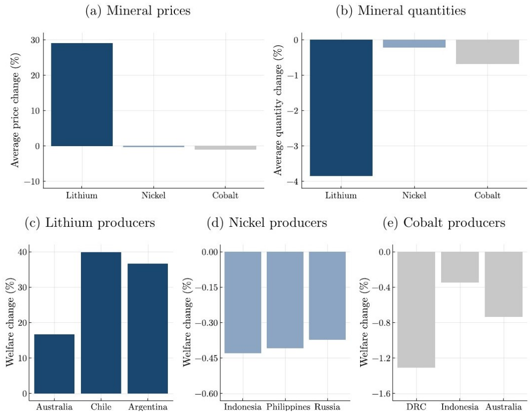
Signature

Negative cross-mineral responses reveal **gross complementarity**.

Counterfactuals (2): Market power within minerals

Case 1: Unilateral lithium policy creates winners within lithium and losers elsewhere

Figure 8: Unilateral lithium policy



- Australia restricts lithium and raises its price.
- Chile and Argentina free-ride and gain even more.
- Nickel and cobalt prices and producer welfare fall.

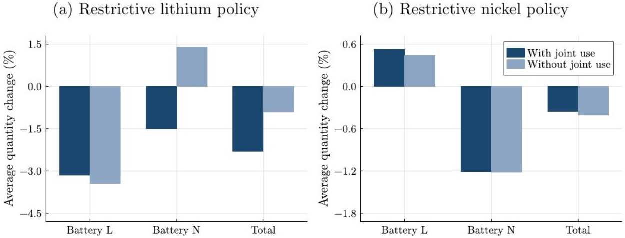
Incidence

Aligned interests among lithium producers; conflict across complementary minerals.

Counterfactuals (2): Market power within minerals

Case 2: Joint use amplifies lithium policy but cushions nickel policy

Figure 9: Green adoption and joint mineral use



Lithium policy

- Common to both batteries.
- Joint use more than doubles the adoption decline.

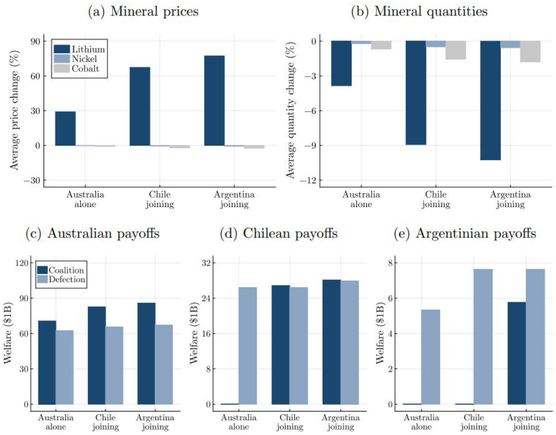
Nickel policy

- Lower lithium demand reduces the LFP price.
- LFP substitution attenuates the decline.

Counterfactuals (2): Market power within minerals

Case 3: Cartel power rises faster than participation incentives

Figure 10: Lithium cartels



- Australia alone: price $+30\%$, quantity -4%.
- Adding Chile more than doubles the market effect.
- Argentina adds little power and prefers to free-ride.

Tension

Broader coalitions increase market power but weaken participation incentives.

Counterfactuals (3): Market power across minerals

Case 1: Multi-mineral cartel internalizes complementarity but creates participation problems

Figure 11: Lithium and nickel cartels

(a) Battery prices (b) Battery quantities

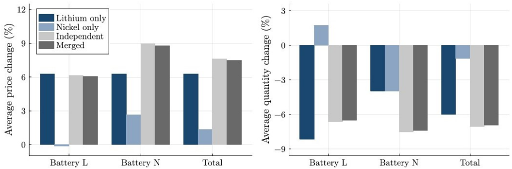
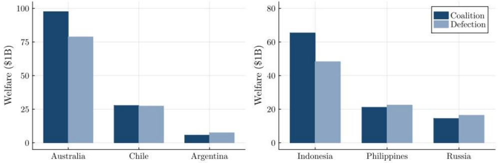


Figure 12: Lithium-nickel cartel cohesion

(a) Defection incentives for lithium (b) Defection incentives for nickel



Economic effect

The merged cartel internalizes two forces: substitution & complementarity, and they nearly offset.

Cohesion

- Australia and Indonesia are anchors.
- Chile participates weakly.
- Argentina, Philippines, and Russia prefer to defect.

Counterfactuals (3): Market power across minerals

Case 2: Chinese ownership spans minerals, but coordination softens upstream power

Figure 13: Market concentration by mine ownership

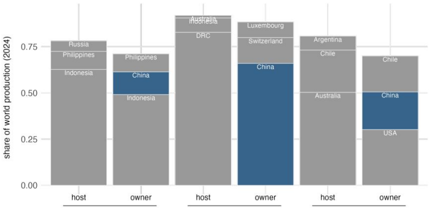
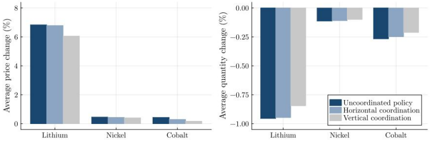


Figure 14: Chinese policy

(a) Mineral prices (b) Mineral quantities

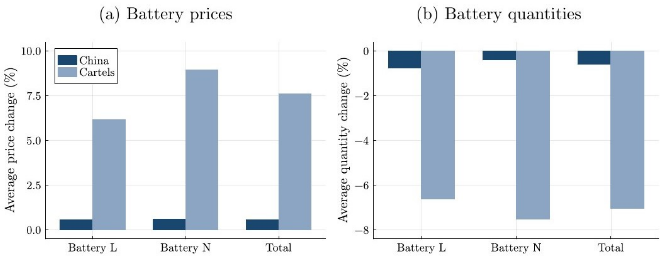


- China is the only owner country with large stakes across all three minerals.
- Horizontal coordination internalizes cross-mineral complementarity.
- Vertical coordination also values downstream Chinese battery welfare.
- Both reduce optimal upstream restrictions.

Counterfactuals (3): Market power across minerals

Case 3: Resource nationalism may shift market power toward host states

Figure 15: Chinese multinationals vs mineral cartels



Country cartels have larger effects because

1. host-country production shares exceed Chinese ownership shares;
2. separate country cartels do not internalize cross-mineral complementarity.

Implication

Host-government control may amplify upstream market power relative to diversified ownership.

Conclusion: Critical minerals and the green transition

1. **Market concentration matters:** A few countries dominate supply, giving them leverage to restrict output.
2. **Interconnected inputs:** Policies on one mineral ripple across others
   - Lithium policy: Restrictive supply hits EV adoption hardest, since it's a common, non-substitutable input
   - Nickel policy: Supply cuts lower lithium prices, partly offsetting the declines of EV adoption.
3. **Coordination has opposing effects.** It strengthens market power within a mineral market, but internalizes complementarity across minerals.

Big picture

Mineral market power cannot be understood mineral by mineral: its incidence depends on joint input use, battery substitution, mine supply responses, ownership, and coalition structure.

Implication

Climate progress depends on managing these concentrated, interconnected markets.

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