

Do rare-earth supply constraints slow the green transition?

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Motivation

Clean energy relies on materials with concentrated supply

- Neodymium and dysprosium form the **permanent magnets** in electric-vehicle motors and wind turbines (Depraeter et al. 2025); a 2-MW wind turbine uses about 360 kg of neodymium and 60 kg of dysprosium (Stover 2011; Burnell 2010)
- Rare earths are **not geologically rare**: the bottleneck is refining and processing
- Mine production: China about **69%** of the world total (U.S. Geological Survey 2025). Refining: the top three countries held 97% of refined output in 2024, China alone **91%** (International Energy Agency 2025)
- Their clean-energy role is concentrated in magnets: not major inputs to silicon solar cells or to lithium-ion battery cells

China has used its position as a geopolitical tool

- **2010:** China tightened rare-earth exports during a dispute with Japan; Japan's import price of rare-earth metals from China rose from about 1,000 to over 20,000 JPY/kg between early 2010 and early 2012 (Morrison and Tang 2012; Vekasi 2019)
- **2023–24:** non-automatic export licensing for critical rare earths and permanent magnets; later, restrictions on seven rare-earth minerals in response to U.S. tariffs
- Supply security became a strategic priority: the U.S. directed over \$440 million under the Defense Production Act toward mining, refining and magnet manufacturing (U.S. Department of Defense 2024)

Question

Can supply constraints in critical materials slow the green transition? What happens to decarbonization investment when key inputs become **scarce or geopolitically restricted**, and how do these constraints propagate across clean-energy supply chains?

What the paper does

- Rare-earth price histories are short and thin (long-term contracts), so it builds a **news-based index**: rare-earth supply concerns in 27 English-language newspapers via Factiva, January 2008 to June 2026, following Baker et al. (2016)
- Estimates a **Bayesian structural VAR** (Minnesota prior, 6 lags) in three models: global macroeconomy, carbon market, critical minerals
- **Identifies** the shock recursively, with the index ordered first, so it is contemporaneously exogenous to the other variables
- Outcomes: EU ETS carbon prices, expected decarbonization investment (Fuchs et al. 2024), global activity, and prices of other critical materials

Reading the evidence

The index measures **perceived** supply risk (news intensity), and the outcome variables are financial indicators, not physical installation volumes.

Preview of results

Following a **rare-earth uncertainty shock**:

- **Expected decarbonization investment declines**; the paper reads this as clean-energy investment becoming less viable
- **Carbon prices rise**, consistent with a higher marginal cost of emissions reduction
- **Lithium prices decline**, through complementarity in clean technologies; the effects reach other critical materials
- The coal-to-gas price ratio rises briefly, global economic activity declines, and geopolitical risk rises

Message of the paper

Concentrated critical-materials supply chains are a vulnerability for the green transition: they weaken the economic case for clean-energy investment.

Related literature and contribution

1. **Carbon markets and the green transition**: critical-mineral prices and the energy transition (Attílio 2025); EU ETS regulation changes as negative supply shocks (Hensel et al. 2024; Känzig 2023); macro effects of climate policy (Metcalf and Stock 2020; Konradt and Mauro 2023); critical-materials requirements (Vivoda and Matthews 2023; Tedeschi 2025)
2. **Supply chain disruptions**: shipping costs and inflation (Benigno et al. 2022; Laumer 2023; Morão 2025); little on the constraints facing clean-energy technologies
3. **Text-based indices** from news (Baker et al. 2016; Caldara, Iacoviello, et al. 2020; Caldara and Iacoviello 2022; Laudati and Pesaran 2022; Bondarenko et al. 2024)

Contribution (paper's three counts)

(i) Supply conditions measured by a **news-based index**, not by thin prices; (ii) the shock identified by ordering the index first in a recursive scheme; (iii) the target is the **green-transition channel**, expected decarbonization investment and EU ETS carbon prices, rather than output or inflation.

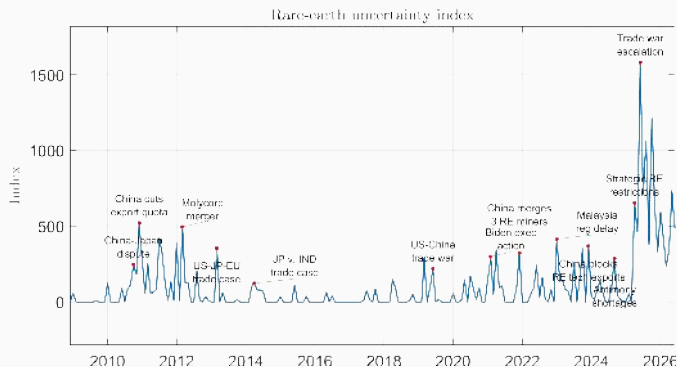
The index

A rare-earth uncertainty index from global news

- A supply constraint is any event or condition that threatens the normal flow of rare earths, **realized or anticipated** (Young et al. 2021; Burriel et al. 2024): export controls, trade disputes, mine closures, regulatory changes
- Share of articles with keywords from two blocks (Baker et al. 2016):
 - **Rare earth**: “rare-earth”, “lanthanide”, “neodymium”, “dysprosium”, ...
 - **Supply**: “shortage”, “scarcity”, “backlog”, “disruption”, “bottleneck”
- A rare-earth keyword in the headline or leading paragraphs; more than 150 words; summaries, calendars, digests, rankings, interviews and commentaries excluded
- Per newspaper and month: qualifying articles over total articles, weighted by source importance, standardized by the newspaper’s own standard deviation, averaged across newspapers, rescaled to a mean of 100
- It measures the **risk of disruption that markets perceive**, not the physical bottleneck itself

Query and sources

The index peaks at documented supply episodes



Notes: Rare-earth uncertainty index, monthly; red dots mark labelled events.

- **2010:** Senkaku dispute, export halt to Japan
- **2015:** Molycorp bankruptcy idles Mountain Pass, the main producer outside China
- **2018–19:** US–China trade tensions
- **2021:** Myanmar coup; Executive Order 14017 on supply chains
- **2025:** licensing on seven medium and heavy rare earths (April); the June escalation gives the **highest value in the index's history**

Events table

Validation: a distinct measure, checked against trade flows

- The largest spikes line up with documented export restrictions, trade disputes and mine closures
- **Low correlation** with existing uncertainty indices, so it captures something they do not (paper's reading):

Index	Correlation
Economic policy uncertainty (EPU)	0.105
Oil price uncertainty (OPU)	−0.058
Trade policy uncertainty (TPU)	−0.032
Energy transportation uncertainty (ETU)	0.053

- Compared with Chinese rare-earth exports (UN Comtrade): peaks coincide with export-restriction episodes; during the 2010–2012 quota period the index rises as export volumes fall
- Export volumes alone are **incomplete**: they mix supply and demand, have reporting gaps, and miss restrictions aimed at heavy rare earths and magnets

Exports vs. index

Model and Data

A Bayesian structural VAR

$$\mathbf{y}_t = \mathbf{a} + \mathbf{A}_1 \mathbf{y}_{t-1} + \dots + \mathbf{A}_p \mathbf{y}_{t-p} + \varepsilon_t, \quad \varepsilon_t = \mathbf{B} \boldsymbol{\eta}_t, \quad \text{Var}(\boldsymbol{\eta}_t) = \boldsymbol{\Omega} \text{ diagonal}$$

- $\mathbf{y}_t$: $n \times 1$ vector of endogenous variables; ε_t : reduced-form disturbances with variance $\boldsymbol{\Sigma} = \mathbf{B}\boldsymbol{\Omega}\mathbf{B}'$; $\boldsymbol{\eta}_t$: structural shocks
- Goal: one column $\mathbf{b}_1$ of $\mathbf{B}$, the effect of the **rare-earth uncertainty shock** $\eta_{1,t}$; the other shocks are not the focus
- **Minnesota prior** with $p = 6$ lags: overall tightness $\lambda_1 = 0.1$, cross-variable weighting $\lambda_2 = 0.1$, lag decay $\lambda_3 = 1$; toolbox of Dieppe et al. (2016)
- Slope prior centered on a random walk; inverse-Wishart prior for $\boldsymbol{\Sigma}$
- Impulse responses: posterior median with **68% credible bands**, horizon in months

Prior details

Identification: the index is ordered first

- The index reu_t is first in all three models: **contemporaneously exogenous** to the other variables
- Concern: the index is news-based, and media may react in the same month to events that also move carbon and mineral prices
- The assumption is not that news is slow. It is that the **supply-side events** behind the index, China's export licensing, mine consolidation and trade-policy announcements, are set by Chinese industrial policy and geological factors that do not respond to same-month EU carbon prices or European clean-energy investment
- Direction: from Chinese supply decisions to global financial markets, not the reverse
- The remaining variables are ordered by how fast they respond to upstream supply information

Ordering checks

Three models, three samples

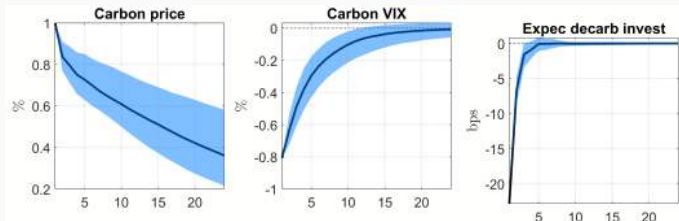
Model	Ordering	Sample
Carbon market	reu_t , carbon price, carbon VIX, climate awareness, transition-metals price, expected decarb. investment, brown stock price	2013m9–2022m12
Critical minerals	reu_t , rare-earth, lithium, cobalt, silicon, manganese, vanadium prices	2012m6–2024m12
Global macro	reu_t , global activity, geopolitical risk, real oil price, critical-materials price, coal-to-gas ratio, oil inventories	2008m1–2024m12

- Carbon variables: Fuchs et al. (2024); global activity: Kilian and Zhou (2018); climate awareness: Ardia et al. (2023); metal prices: IMF
- The decarbonization variables are **European (EU ETS) or global financial indicators**: they capture expectations and sentiment, not physical deployment

Variables Data series Rare-earth uses

Results

Carbon prices rise and expected decarbonization investment falls

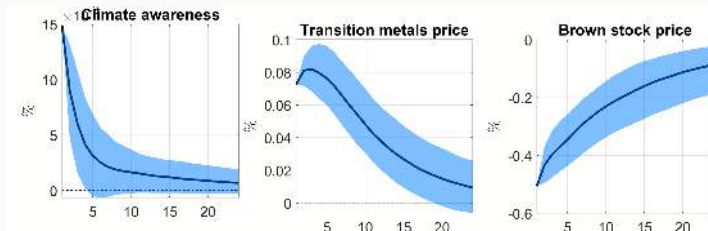


Notes: Normalized to raise carbon prices by 10% on impact; median and 68% bands, months.

- **Carbon price:** +10% on impact, about 4% by month 20, band above zero; read as a higher marginal cost of emissions reduction
- **Carbon VIX:** about -8% on impact, back toward baseline by month 20 (paper: markets learn the feasible pace of emissions reduction)
- **Expected decarbonization investment:** falls sharply on impact, then recovers toward baseline within a few months

Ordering checks

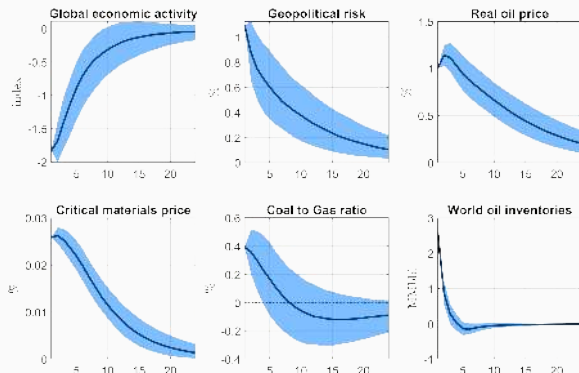
Other carbon-market variables



Notes: Same shock and normalization as the previous slide.

- **Climate awareness** (media concern): rises on impact, short-lived; the band includes zero after about four months. The paper reads it as awareness of the transition's vulnerability
- **Transition-metals prices:** up on impact, hump-shaped, back to zero by about the end of the second year: a temporary spillover
- **Brown stock prices:** fall on impact (about -5%), then partly recover; the paper reads this as broad negative effects including carbon-intensive industries

Macro: activity falls, geopolitical risk and oil prices rise

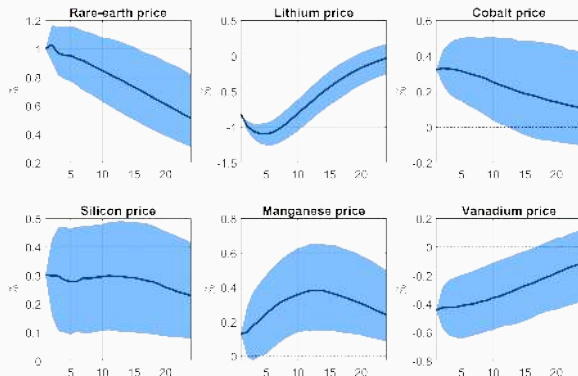


Notes: Normalized to raise the real oil price by 1% on impact; median and 68% bands, months.

- **Global activity:** falls on impact, about -1 by month 5, then recovering toward zero
- **Geopolitical risk:** rises on impact and decays; the paper reads it as recognition of supply vulnerability
- **Real oil price:** peaks slightly above the 1% normalization, then normalizes
- **Coal-to-gas ratio:** $+0.4\%$ on impact, significant for a few months only. A **relative price, not a change in the generation mix:** no sustained shift to coal or to gas
- **Oil inventories:** up on impact, then normalize

Variance shares

Other critical materials: complementarity dominates



Notes: Normalized to raise the rare-earth price by 10% on impact; median and 68% bands, months.

- **Rare-earth price:** about 5% above baseline at month 24, band above zero throughout. A consistency check inside the same system, **not independent validation**
- **Lithium:** falls to about -11% around months 5–6, back toward zero by month 24: complementarity in clean technologies
- **Cobalt, silicon, manganese:** positive responses (about 3%, 3%, up to 4%); the paper offers substitution as one reading
- **Vanadium:** about -4.5% on impact, recovering toward zero
- Overall, demand destruction outweighs substitution (paper's reading)

Expected responses

What the results do and do not say

- The outcomes are **financial indicators**: the paper reads the results as the economic viability and investor expectations of decarbonization, **not physical installation rates**
- The shock is an **uncertainty shock** identified from news; it reflects perceived supply risk rather than a measured physical cut
- In the global macro model, the shock explains about three quarters of the variance of the index itself, and around 8–12% of the variance of each macroeconomic and commodity variable; the oil price shows no measurable response on impact
- The paper also stresses that the carbon-VIX decline differs from a direct supply shock to carbon markets, which would raise uncertainty

Variance shares

Robustness: the main findings remain stable, per the paper

- **Ordering** (carbon-market model): other variables reordered three ways; impact responses identical, paths differ only by sampling noise
- **Euro Area variables**: same signs; the coal-to-gas response is larger (about 2.3% against 0.4%)
- **Excluding crisis periods** (the war; the pandemic and the war): similar patterns, per the paper
- **Specification**: ETU, OPU and OPEC-news exogenous variables; 9 and 12 lags; block exogeneity; optimized hyperparameters; no sum-of-coefficients or cointegration prior; no trend; no constant

Scope

The sensitivity figures in the paper's appendix are for the **global macroeconomic model**; the carbon-market model is checked for ordering.

Ordering Euro Area Crisis periods OPEC 12 lags No trend

Conclusion

Policy implications, as the paper argues

- Critical-materials constraints are a **limit on clean-technology deployment**: when inputs are scarce or restricted, the economics of the transition worsen
- Climate policy design should account for material constraints. Three levers:
 1. **Supply-chain diversification**: domestic critical-materials processing, partnerships with several supplier countries
 2. **Recycling** and circular-economy policies to reduce dependence on primary extraction
 3. **R&D** on technologies that need fewer critical materials or use more abundant substitutes
- Material supply-chain policy is a **complement** to climate policy, not a separate concern

- The index captures **perceived supply risk** from news, not the physical bottleneck; results are about **financial expectations** (European or global indicators), not installation rates
- Identification rests on the **assumption** that the index is contemporaneously exogenous to the other variables
- The rare-earth sample is short and data-sparse; the carbon-market model runs 2013m9–2022m12
- The coal-to-gas ratio is a short-lived relative price, not a measured change in the generation mix; the rare-earth price response is a consistency check, not independent validation

Next step, per the paper

How diversification strategies and international cooperation can strengthen the resilience of green-transition supply chains and manage critical materials as global public goods for climate action.

Conclusion

- A **rare-earth uncertainty index** from global news and a Bayesian SVAR trace how the shock propagates through energy and materials markets
- The shock is followed by **lower expected decarbonization investment** and **higher carbon prices**, consistent with a higher marginal cost of emissions reduction
- Effects reach other critical materials: **lithium prices decline** through complementarity in clean technologies
- Concentrated supply chains are a **vulnerability** for the green transition: they weaken the economic case for clean-energy investment

Thank you!

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Backup

Index construction: keywords, query and sources

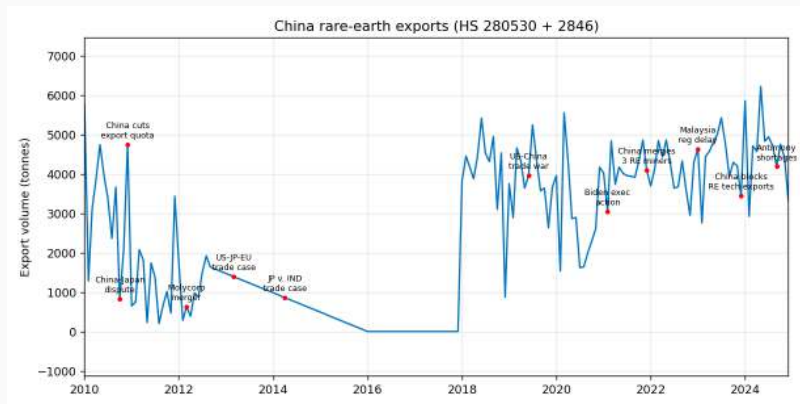
- Source: Dow Jones Factiva, English-language news, January 2008 to June 2026; the duplicates option drops identical and near-identical republications
- Rare-earth keywords: “rare-earth”, “lanthanide”, “neodymium”, “dysprosium”, “praseodymium”, “terbium”, “europium”, “yttrium”, “samarium”, “cerium”, “lanthanum”, “scandium”. The umbrella terms catch any rare-earth article; promethium is excluded (radioactive, not traded)
- Supply keywords: “shortage”, “scarcity”, “backlog”, “disruption”, “bottleneck”
- Terms like “shortage” could describe a demand-driven tightening; the paper says the largest movements align with supply-side episodes (export quotas, licensing restrictions, mine closures), not demand booms
- **27 newspapers:** 6 in North America (e.g. The New York Times, The Wall Street Journal), 7 in Europe (e.g. Financial Times, The Guardian), 14 in Asia-Pacific (e.g. South China Morning Post, Kyodo News, China Daily); all cover 2008-01 to 2026-06
- The paper’s Factiva query is given in full in its footnote; the construction code is in the replication package

Contribution of specific events to the index

Peak	Event	Index	Share of year
2010m12	China–Japan Senkaku dispute; export halt to Japan	520.5	38%
2011m7	Molycorp merger; tighter Chinese export restrictions	419.5	24%
2012m3	US–Japan–EU WTO cases against China’s export limits	494.3	35%
2015m6	Molycorp bankruptcy; Mountain Pass idled	109.9	61%
2019m3	US–China trade war	292.3	47%
2021m2	Myanmar coup; heavy rare-earth feedstock disrupted	298.1	21%
2021m4	Biden executive action on supply chains	343.9	24%
2024m9	China restricts critical-materials exports (antimony)	288.0	38%
2025m4	Export licensing on seven strategic rare earths	653.0	9%
2025m6	Trade-war escalation (highest value in sample)	1580.5	22%

Notes: Index: standardized value in the peak month; share of year: the peak month’s share of that calendar year’s total.

Index and Chinese rare-earth exports

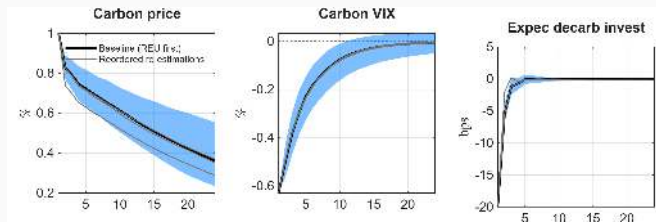


Notes: Monthly Chinese rare-earth exports, UN Comtrade (HS 280530 and 2846), with the labelled events. The paper notes the export series contains reporting gaps.

Estimation details

- Reduced-form parameters: Minnesota prior with standard shrinkage; more shrinkage on distant lags and on coefficients linking variables a priori less likely to be related
- Prior on slope coefficients β : normal, mean centered on a random walk, diagonal covariance Ω_0 scaled by the residual variance of a preliminary full VAR with all variables and lags
- Prior on Σ : inverse-Wishart with scale matrix S_0 and degrees of freedom ν_0
- Hyperparameters: $\lambda_1 = 0.1$, $\lambda_2 = 0.1$, $\lambda_3 = 1$; lag length $p = 6$ in the main specification
- Sensitivity to these choices: hyperparameters optimized, no sum-of-coefficients prior, no cointegration prior, 9 and 12 lags (see robustness)

Ordering: residual correlations and re-estimation



Notes: Carbon-market model; black: baseline (*reu* first, 68% band); grey: three re-estimations with the other six variables reordered.
Panels cropped from the paper's appendix figure.

- Largest correlation of the *reu* innovation with any other: **0.19** (macro), **0.31** (carbon market), **0.11** (minerals)
- Every residual correlation stays below 0.4
- The paper notes these do not by themselves show the ordering is immaterial, so it re-estimates the carbon-market model directly
- Impact responses are identical across orderings; paths differ only by posterior sampling noise

Variables: index and global macro model

Symbol	Variable	Definition	Source
reu_t	Rare-earth uncertainty index	News index of rare-earth supply concerns; 27 newspapers via Factiva	Own
Δy_t^w	Global real activity	Index from dollar-priced bulk dry cargo freight rates	Kilian and Zhou (2018)
ζ_t	Geopolitical risk	Newspaper-based index of geopolitical events and uncertainty	Caldara and Iacoviello (2022)
p_t^o	Real oil price	US refiners' acquisition cost of imported crude, deflated by US CPI	US EIA
p_t^{crit}	Critical-materials price	First principal component of copper, nickel and zinc prices	Own / World Bank
$p_t^{coalgas}$	Coal-to-gas ratio	Ratio of coal to natural gas prices in power generation	Own / World Bank
Δi_t^w	Oil inventories	Change in OECD and US crude and petroleum stocks, following Kilian and Murphy (2013)	US EIA

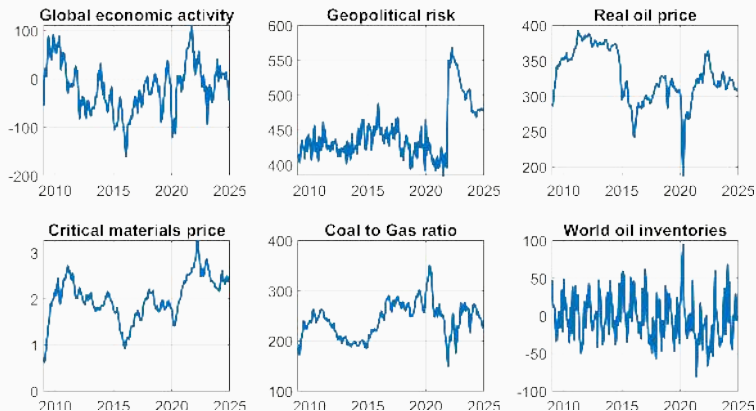
Notes: All series monthly; the index spans 2008m1–2026m6. [Next: carbon and minerals](#)

Variables: carbon market and critical minerals models

Symbol	Variable	Definition	Source
p_t^{carb}	Carbon price	EU ETS carbon emission certificate price	Fuchs et al. (2024)
vix_t^{carb}	Carbon VIX	Implied volatility of EU ETS carbon prices	Fuchs et al. (2024)
$aware_t^{clim}$	Climate awareness	Media Climate Change Concerns index	Ardia et al. (2023)
inv_t^{decarb}	Expected decarbonization investment	Market-based measure of expected clean-energy deployment	Fuchs et al. (2024)
p_t^{trans}	Transition-metals price	Index of metals used in a net-zero scenario	IMF
p_t^{brown}	Brown stock price	Relative equity performance of carbon-intensive oil and gas firms	STOXX
$p_t^{rare}, p_t^{lith}, p_t^{cob}$	Rare-earth, lithium, cobalt prices	Commodity prices from 2012m6	IMF
$p_t^{sil}, p_t^{mang}, p_t^{van}$	Silicon, manganese, vanadium prices	Commodity prices from 2012m6	IMF

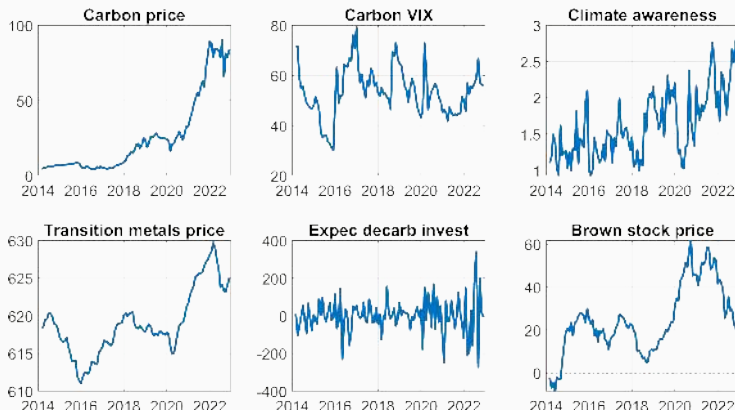
Notes: All series monthly; samples as on the data slide.

Data series in the baseline models (1/3)



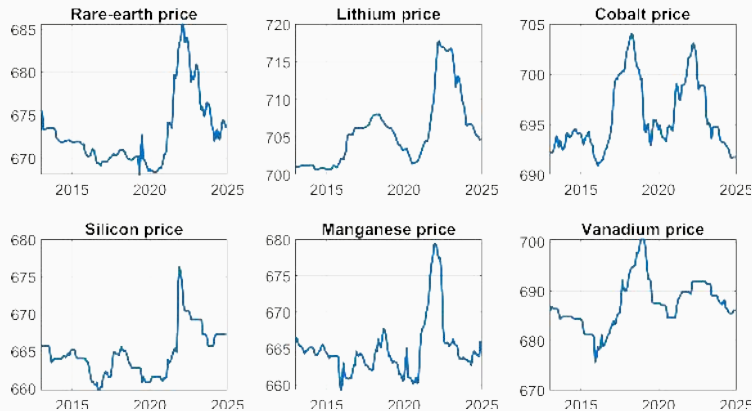
Notes: Global macro model series, from the paper's appendix.

Data series in the baseline models (2/3)



Notes: Carbon market model series, from the paper's appendix.

Data series in the baseline models (3/3)



Notes: Critical minerals model series, from the paper's appendix.

Rare-earth elements used in clean-energy technologies

Element	Symbol	Main clean-energy use	Named in keywords
Neodymium	Nd	Permanent magnets (wind turbines, EV motors)	Yes
Praseodymium	Pr	Permanent magnets	Yes
Dysprosium	Dy	High-temperature magnet additive	Yes
Terbium	Tb	Magnet additive; phosphors	Yes
Samarium	Sm	Samarium-cobalt magnets	Yes
Lanthanum	La	NiMH batteries; catalysts	Yes
Cerium	Ce	Catalysts; NiMH batteries	Yes
Yttrium	Y	Phosphors; solid-oxide fuel cells	Yes
Europium	Eu	Phosphors	Yes
Scandium	Sc	Solid-oxide fuel cells; Al-Sc alloys	Yes
Other (Gd, Ho, Er, Tm, Yb, Lu)	—	Niche or minimal clean-energy use	Umbrella

Critical minerals: clean-energy use and link to rare earths

Commodity	Clean-energy use	Link to rare earths	Expected response
Rare earths	Permanent magnets for EV motors and wind turbines	Upstream input; the shock variable	Rise (direct)
Lithium	Batteries and energy storage	Complement, co-used in clean technologies	Fall
Cobalt	Battery cathodes	Substitute in battery chemistries	Substitution
Silicon	Solar PV modules	Complement, co-required in solar	Fall
Manganese	Steel and alternative battery materials	Substitute	Substitution
Vanadium	Redox-flow energy storage	Substitute, competing storage technology	Substitution

Notes: As in the paper's appendix table. The ordering places rare earths first as the upstream bottleneck, then lithium, then the more substitutable minerals. In the estimated responses silicon is positive, not a fall.

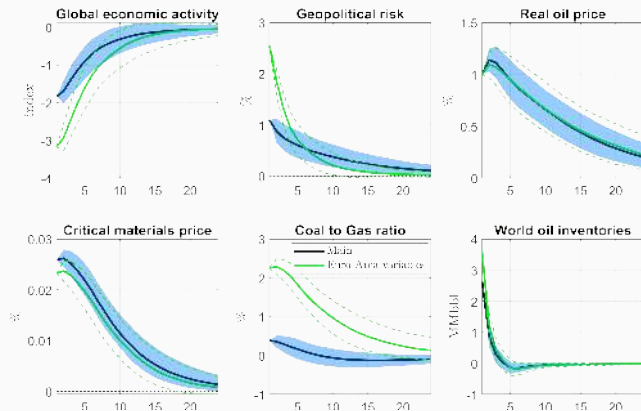
Variance decomposition: global macro model

Horizon	reu_t	Δy_t^w	ζ_t	p_t^o	p_t^{crit}	$p_t^{coalgas}$	Δi_t^w
1	77.63	10.67	9.03	0.00	12.11	10.48	9.43
6	77.33	10.43	8.82	0.09	11.34	10.63	9.36
12	76.81	10.40	8.79	0.22	10.94	10.35	9.37
24	76.47	10.19	8.62	0.36	10.71	10.09	9.40

Notes: Percentage of the h -step-ahead forecast error variance of each column variable explained by the rare-earth uncertainty shock, at the posterior median. Horizon 1 is the impact period; the oil price shows no measurable contemporaneous response.

- The shock explains about three quarters of the variance of the index itself and roughly 8–12% of each macro and commodity variable (oil price excepted)

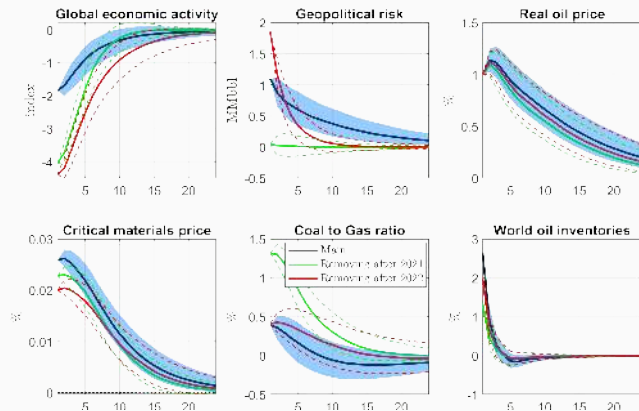
Robustness: Euro Area variables



Notes: Benchmark (black, 68% band) against the Euro Area model (green).

- Brent deflated by Euro Area inflation; geopolitical risk from Bondarenko et al. (2024); coal-to-gas from South African coal and Dutch TTF gas
- Same signs across specifications
- Larger initial responses in the Euro Area for geopolitical risk and the coal-to-gas ratio (about 2.3% against 0.4%); the paper links this to Europe's energy-market structure

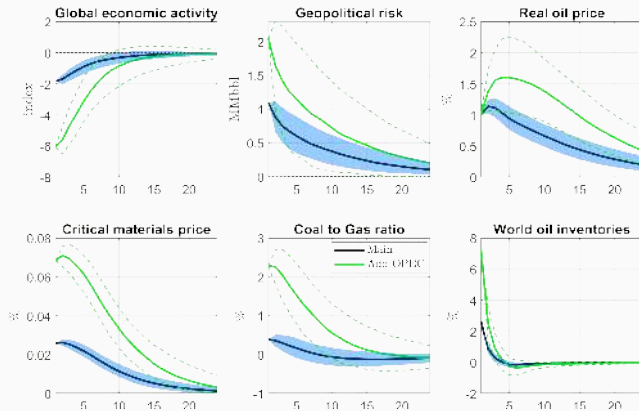
Robustness: dropping post-crisis periods



Notes: Main model against two shorter samples; legend as in the paper's figure.

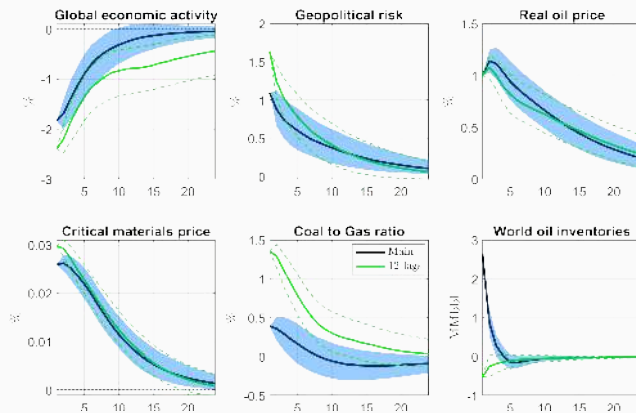
- The paper estimates the model without the post-pandemic and post-invasion periods
- Paper's reading: similar patterns across sample periods, so the channels do not depend on recent crisis conditions
- In the figure, the impact responses of global activity and of geopolitical risk differ from the main model in the shorter samples

Robustness: OPEC news as an exogenous variable



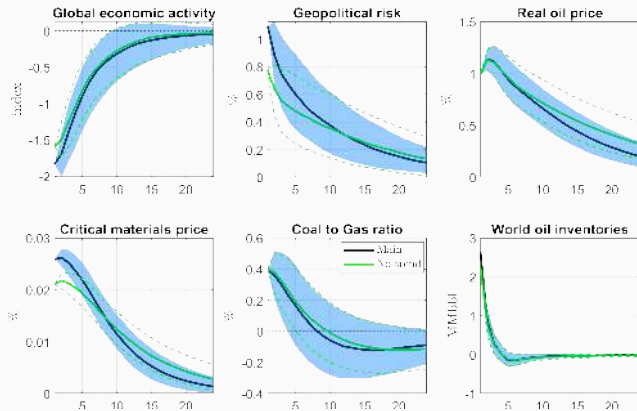
Notes: Global macro model, main (black, 68% band) against the model adding OPEC news shocks (green).

Robustness: 12 lags



Notes: Global macro model, main (black, 68% band) against a BVAR(12) (green).

Robustness: no linear trend



Notes: Global macro model, main (black, 68% band) against a BVAR without a linear trend (green).

References i

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