Can strategic dependencies harm the acceleration towards net-zero transitions? The case of lithium-ion battery industry

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Outline

Motivation and contribution

Data and methodology

Trade and innovation
along the supply chain

Econometric estimates

Findings and Policy Implications

Motivation and contribution

The green transition in an increasingly polarized world order

- ✓ **Accelerating the energy transition** is a matter of utmost urgency (i.e., growing pressure of climate change, need to pursue energy autonomy), but:
- ✓ It is **constrained by the asymmetric distribution** of critical raw materials (CRMs), manufacturing capacity and technological capabilities
- ✓ The rise of **a polarized 'world order'**, in context of fragmented supply chains, **exacerbates these constraints** (Rodrik and Walt, 2022)
- ✓ Countries face a **trade-off between embedding in the international division of labour to accelerate the green transition and pursuing strategic autonomy and economic security objectives**.
- ✓ **Innovation and industrial policies could help overcome these bottlenecks and accelerate decarbonisation** processes.

Background framework

Research Policy
Volume 52, Issue 6, July 2023, 104765

Technology sovereignty as an emerging frame for innovation policy. Defining rationales, ends and means

Jakob Edler[a,b], Knut Blind[a,c], Henning Kroll[a,d], Torben Schubert[a,e]

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Intereconomics, 2025, 60(2), 73-80
JEL: F52, O32

Francesco Crespi, Rosario Cerra and Francesco Zezza

Coopetitive Technological Sovereignty: A Strategy to Reconcile International Collaboration with Knowledge and Economic Security

Energy Research & Social Science
Volume 121, March 2025, 103948

Review

The acceleration of low-carbon transitions: Insights, concepts, challenges, and new directions for research

Benjamin K. Sovacool, Frank W. Geels, Allan Dahl Andersen, Michael Grubb, Andrew J. Jordan, Florian Kern, Paula Kivimaa, Matthew Lockwood, Jochen Markard, James Meadowcroft, Jonas Meckling, Brendon Moore, Rob Raven, Karoline S. Rogge, Daniel Rosenbloom, Tobias S. Schmidt, Johan Schot, Darren Sharp, Janet Stephenson, Irja Vormedal, Kejia Yang

Journal of Cleaner Production
Volume 434, 1 January 2024, 140222

Technological sovereignty and strategic dependencies: The case of the photovoltaic supply chain

Serenella Caravella[a], Francesco Crespi[b], Giacomo Cucignatto[c], Dario Guarascio[c]

Background literature and contribution

- **Literature gaps:**
  - Few papers have provided a thorough mapping of critical green supply chains, including LB (Malhotra et al., 2021).
  - Most of the works stop at a level of aggregation that fails to identify the most critical products and technologies.
- Building on Caravella et al. (2024), **this work** adds to the literature by:

  1. developing a **granular mapping** of countries' positioning along the LBSC and its evolution, **looking at both trade and technology (patent)**

  2. identifying, through a **product-level 'intelligence'** (Edler et al. 2023), the segments in which **bottlenecks** and **dependencies** are stronger, and consequently areas for policy action

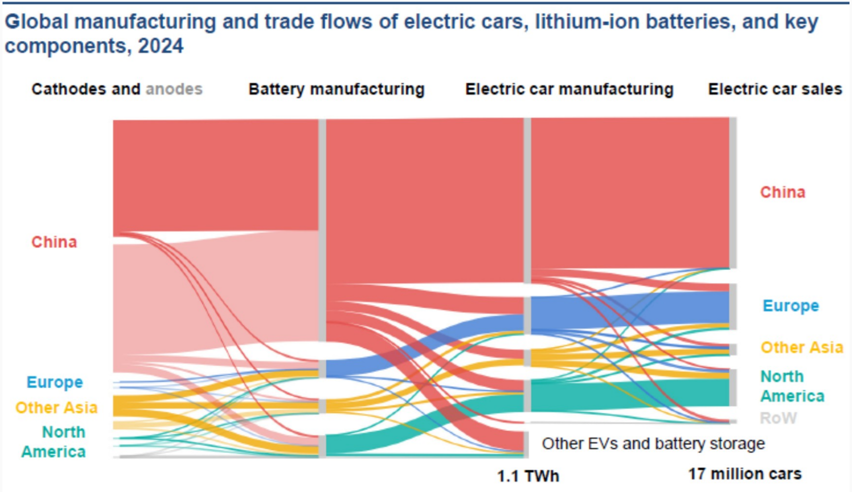
  3. making the case for a **balanced policy mix** that could help overcome technological, productive, and geopolitical obstacles to the faster achievement of net-zero targets

The case of Lithium-ion Batteries Supply Chain

- Focusing on the Lithium-ion Batteries Supply Chain (LBSC) to empirically address: the **acceleration-dependency trade-off**, the role of technological capabilities in shaping competitiveness and the effect of environmental policy stringency

- **LB are crucial in determining the success and timing of the energy transition:**
  i) key to de-carbonize relevant and highly polluting sectors (e.g. automotive)
  ii) growing efficiency and applications in energy storage

- **There are increasing tensions along the LBSC**, driven by concentration, hierarchical reshuffling, and strategic autonomy concerns (Carrara et al. 2023)



Source: IEA (2025)

China covers **80%** of the world's battery production with a near-monopoly in component production.

Technological specialization and structural dependencies

- In 2024, battery prices fell by **30%** in China compared to 10-15% in the EU and the US (IEA, 2025).

- Competition, economies of scale, and innovation have been crucial to greater cost reductions for Chinese producers.

The effects of lacking policies and low competitiveness in Europe

FINANCIAL TIMES

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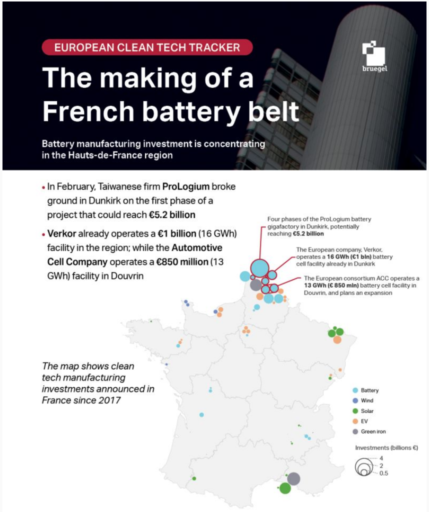
Europe's Climate Leaders

Batteries + Add to myFT

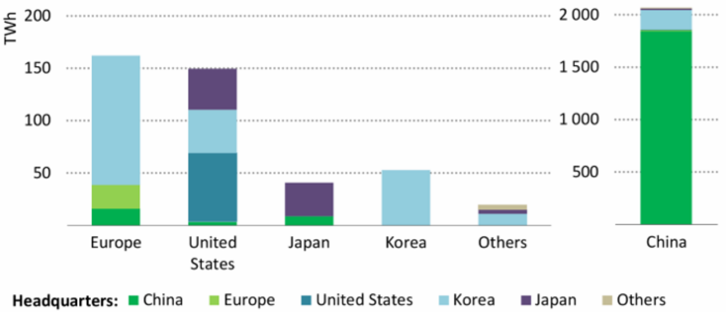
Northvolt failure raises stakes for Europe's battery industry

Swedish start-up's fate raises fears its European peers will also perish in the 'valley of death'



Headquarter ownership of manufacturing capacity in the main countires

Figure 1.21 ▷ Lithium-ion battery manufacturing capacity by manufacturers' headquarter locations, 2023



Battery producers in Korea lead as primary investors in overseas markets with over 350 GWh of manufacturing capacity, followed by Japan and China

Note: TWh = terawatt-hours. Battery manufacturing capacity refers to battery cells.

Source: IEA analysis based on Benchmark Minerals data.

Research questions

- *RQ1* — Which structural changes have characterised the global LBSC over the past twenty years?
- *RQ2* — What are the areas of the LBSC (i.e., stages, product components) where the competitive gap has widened the most?
- *RQ3* — Does the strengthening of technological capabilities enhance the competitive position of economies, potentially reducing their import dependency?
- *RQ4* — Does environmental policy stringency lead to greater import dependency?

Data and methodology

Data and methodology (1)

- **Data Sources**
  - Trade: BACI-UNComtrade
  - Patent: OECD Regpat, PCT
  - Countries: United States, EU, Japan, South Korea, and China
  - Period: 2002-2022
- **Methodology**
  - Identification of HS products' code through in-depth literature review (e.g., McMahon, 2022)
  - Selection of CPC patent classes using a query retailed on each HS product through the EPO research tool
  - Filter the CPC classes based on literature review and applicants main activity
  - Expert validation
- **Fine-grained mapping**
  - 44 HS product codes (6-digit)
  - 153 CPC patent classes (full-digit) spanning over 45,045 patents
  - 27 HS-CPC combinations
  - 6 stages of the LBSC

The LB production process: a snapshot

Mining	Extraction of raw ores/material required for battery materials
Raw material processing	Processing and refining of raw material into precursors for battery materials
Cell component production	Manufacture of specialised battery components: cathode and anode materials, electrolytes, separators and casings
Battery cell/packs production	Fabrication of battery cells, then integration into battery pack including electronics, sensors and battery management system
Battery storage	Battery storage enables integration of variable renewables in low-emissions power systems, ensuring reliable electricity supply
Electric vehicles	EVs are pivotal for decarbonising transport sector and reducing reliance on oil, offering substantial efficiency gains
Recycling/Reuse	Recovery of minerals, cathodes, anodes and/or reuse of used batteries in storage applications

Source: IEA, 2024

The LBSC: fine-grained mapping

Stage	Product description	HS product code (rev. 2022)	CPC patent code
1. Raw Materials	Graphite, natural	250410, 250490	C01B32/20, C01B32/21, C01B32/215, C01B32/22, C01B32/225, C01B32/23, H01M4/625
	Lithium ores	253090	C22B26/12, H01M4/382, H01M4/405
	Manganese ores	260200	C22B47/00, C22B47/0018, C22B47/0027, C22B47/0036, C22B47/0045, C22B47/0054, C22B47/0063, C22B47/0072, C22B47/0081, C22B47/009
	Nickel and Cobalt ores	260400, 260500, 750110, 750210, 750220, 750400, 810520	C22B23/00, C22B23/005, C22B23/02, C22B23/021, C22B23/023, C22B23/025, C22B23/028, C22B23/04, C22B23/0407, C22B23/0415, C22B23/0423, C22B23/0438, C22B23/0446, C22B23/0453, C22B23/0461, C22B23/0469, C22B23/0476, C22B23/0484, C22B23/0492
	Lithium carbonates	283691	C01D15/08
2. Refined Materials	Manganese oxides	282010, 282090	C01G45/02, C08K2003/2262, C25B1/21, H01M4/50, H01M4/502
	Lithium oxides	282520	C01D15/02
	Nickel and Cobalt oxides	282200, 282540, 750120	C01G51/04, C01G53/04, H01M4/52, H01M4/521, H01M4/523
	Nickel chlorides	282735	C01G53/09
	Chlorides (including lithium)	282739	C01D15/04
	Nickel sulphates	283324	C01G53/10, C22B23/043
	Sulphates (including manganese)	283329	C01G45/10
	Nickel and Cobalt waste and scrap	750300, 810530, 810590	C01G51/003, C22B23/06, C22B23/065, C25C1/08
	Manganese waste and scrap	811100	C25C1/10, C25C3/30
3. Machinery	Machines, including roll manufacturing	847989	H01M10/0404, H01M10/0409, H01M4/0435
4. Cell Components	Fluorides (including lithium)	282619, 282690	C01B25/455, C01D15/005
	LMO	284169	C01G45/1228, C01G45/1235, C01G45/1242, C01G45/1257, H01M4/505
	LCO	284190	C01G51/42, H01M4/525
	LFP,NCA,NCM,LNO	284290, 382499	C01B25/375, C01G51/44, C01G51/50, C01G51/52, C01G51/54, C01G51/56, C01G51/58, C01G51/60, C01G51/62, C01G51/64, C01G53/42, C01G53/44, C01G53/50, C01G53/52, C01G53/54, C01G53/56, C01G53/58, C01G53/60, C01G53/62, C01G53/64, H01M10/4242, H01M4/485, H01M4/58, H01M4/581, H01M4/5815, H01M4/582, H01M4/5825
	Phosphides, precursors for NCA and NCM	285390	C01B25/08, C01B25/081, C01B25/088, H01M4/5805
	Graphite, artificial	380110, 380120, 380190	C01B32/205, C04B35/52, C04B35/521, C04B35/522, C04B35/524, C04B35/528, C04B35/532, C04B35/536, H01M4/583, H01M4/5835, H01M4/587
	Plastics, in roll	391910	B29C53/581, B29C53/582, B29K2023/12, B29K2623/12, B32B2323/10, H01M50/403, H01M50/406, H01M50/417, H01M50/449, H01M50/451, H01M50/454, H01M50/457
	Aluminium foil	760720, 761699	B21B1/40, B21B2003/001, B32B15/20, H01M4/661, H01M4/662, H01M4/667
	Cells	850790	H01M4/0404, H01M4/366, Y10T29/49115
	Electrodes	854519	H01M4/13, H01M4/131, H01M4/1315, H01M4/133, H01M4/136, H01M4/137, H01M4/139, H01M4/1391, H01M4/13915, H01M4/1393, H01M4/1397, H01M4/1399
5. Battery	Li-ion Batteries	850760	H01M10/052, H01M10/0525
6. Recycling	Waste and scrap of batteries	854913	H01M10/54, Y02W30/84

Source: authors' elaborations.

Data and methodology (2)

- **Import dependency indicator - IDEP (Gehringer, 2023):**
  Normalized Trade balance (import-exports, *NTB*), local import share from the main supplier (*IMPshMS*), and global export share of the main supplier (*EXPshMS*):

$$IDEP_{c,k,t} = NTB_{c,k,t} \frac{IMPshMS_{c,k,t} + EXPshMS_{c,k,t}}{2} \tag{1}$$

  (Alternative IDEP uses HHI imp and HHI exp consistently with EC, 2021, and Arjona et al., 2023)

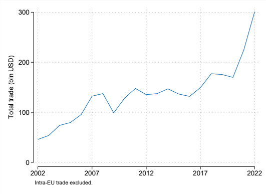
- **Revealed Technological Advantage - RTA (Balassa-type)**
  based on the number of patents, computed with double-fractional accounting (*PCT*):

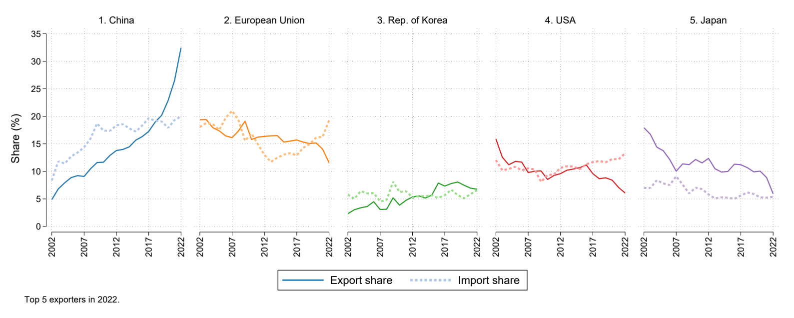
$$RTA_{c,k,t} = \frac{\frac{PCT_{c,k,t}}{\sum_{j=1} PCT_{c,j,t}}}{\frac{\sum_{i=1} PCT_{i,k,t}}{\sum_{i=1}\sum_{j=1} PCT_{i,j,t}}} \tag{2}$$

- **Environmental Policy Stringency - EPS (OECD - Kruse et al. 2022)**
  It measures how strict a country's environmental policies are in reducing pollution and encouraging cleaner production, by incorporating the intensity of different policy instruments (taxes, limits, trading systems, etc.)

Trade and innovation along the supply chain

Trade and Innovation along the supply chain: trade





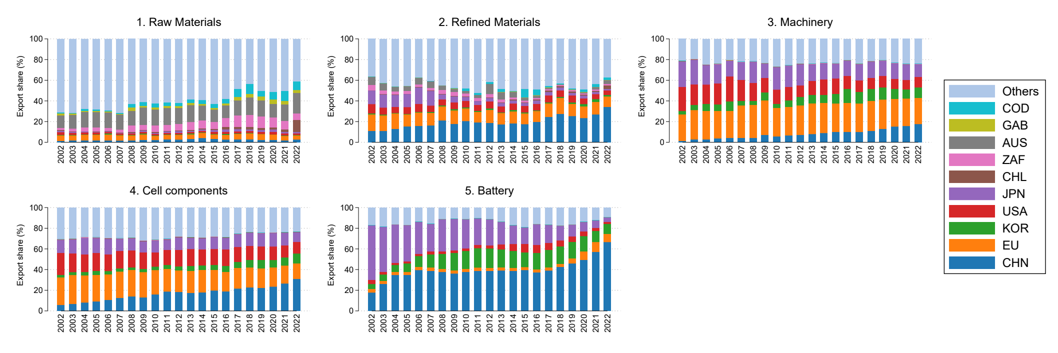
Note: the figures exclude intra-EU trade. Source: elaborations on BACI data.

Trade along the value chain

1. **Raw materials**: endowments
2. **Refined mat.**: China's historically relevant
3. **Machinery**: EU, Japan and the US

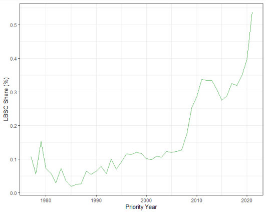
4 **Components**: China and Korea expand

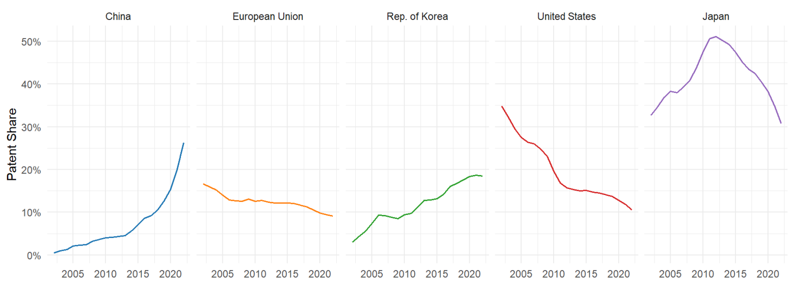
5 **Battery**: China's expansion and mkt power



Source: authors' elaborations on BACI data.

Trade and Innovation along the supply chain: innovation

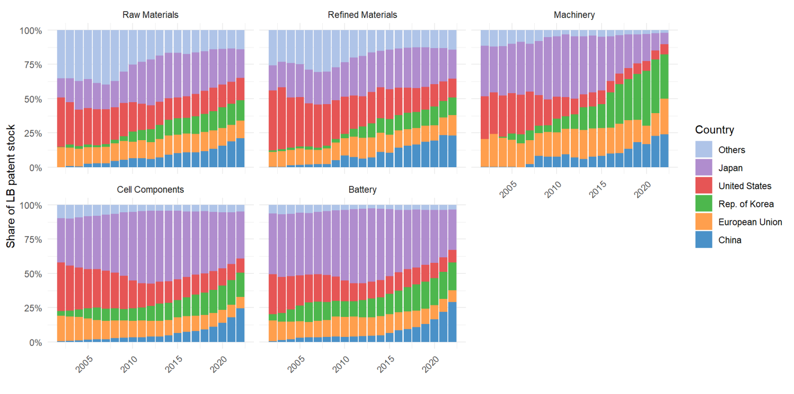




Source: authors' elaborations on OECD REGPAT data.

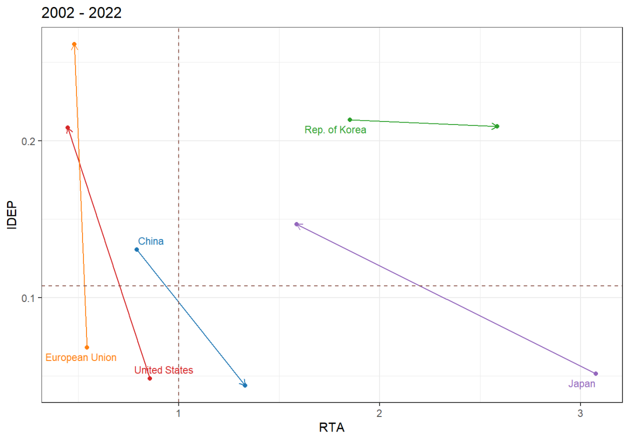
Innovation in the LBSC stages

- Japan is the main innovator along the supply chain, but is declining
- China is the dominant emerging player across all production stages, especially in recycling
- South Korea is also rising, especially in machinery
- US and the EU are losing their innovative shares



Source: authors' elaborations on OECD REGPAT data.

Innovation and Dependency



The figure refers to the whole LBVC. The horizontal red dashed line represents the median of IDEP.

Source: authors' elaborations on OECD REGPAT and BACI data.

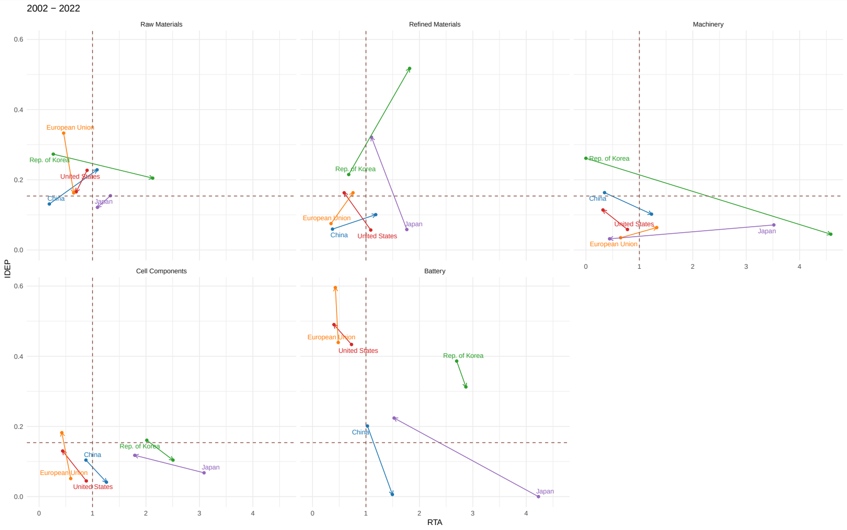
SE quadrant – Strong position. Countries in the southeast quadrant are structurally well positioned to compete in the LBSC, exhibiting low dependency and strong technological capabilities.

SW quadrant – Marginal players. Countries with low participation in the value chain (low dependency but also marginal innovation) cluster in the southwest quadrant.

NW quadrant – Critical position. The northwest quadrant signals problematic positions and priority areas for improvement, as it includes countries with high dependency and low technological competitiveness.

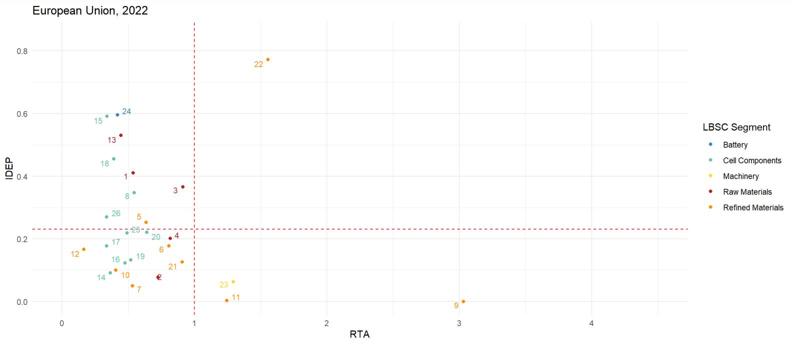
NE quadrant – Structural transformation. Finally, the northeast quadrant includes countries undergoing structural transformation – characterised by high RTA values but still significant dependency.

Innovation and Dependency



Source: authors' elaborations on OECD REGPAT and BACI data.

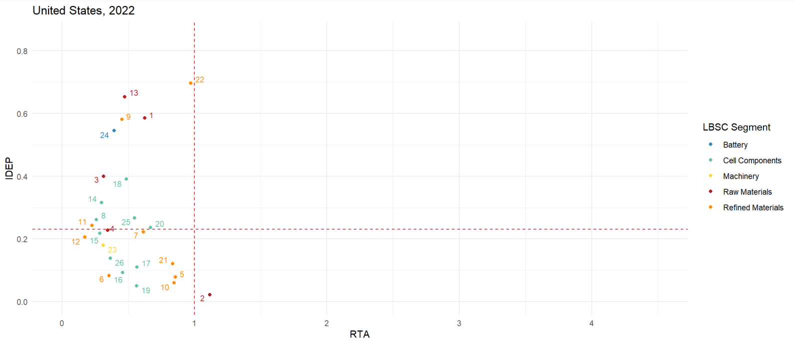
Product-level intelligence: EU



Source: authors' elaborations on BACI and OECD REGPAT data.

Products labels: 1 - Graphite, natural; 2 - Lithium ores; 3 - Manganese ores; 4 - Nickel and Cobalt ores; 5 - Manganese oxides; 6 - Lithium oxides; 7 - Nickel and Cobalt oxides; 8 - Fluorides (including lithium); 9 - Nickel chlorides; 10 - Chlorides (including lithium); 11 - Nickel sulphates; 12 - Sulphates (including manganese); 13 - Lithium carbonates; 14 - LMO; 15 - LCO; 16 - LFP,NCA,NCM,LNO; 17 - Phosphides, precursors for NCA and NCM; 18 - Graphite, artificial; 19 - Plastics, in roll; 20 - Aluminium foil; 21 - Nickel and Cobalt waste and scrap; 22 - Manganese waste and scrap; 23 - Machines, including roll manufacturing; 24 - Li-ion Batteries; 25 - Cells; 26 - Electrodes

Product-level intelligence: US



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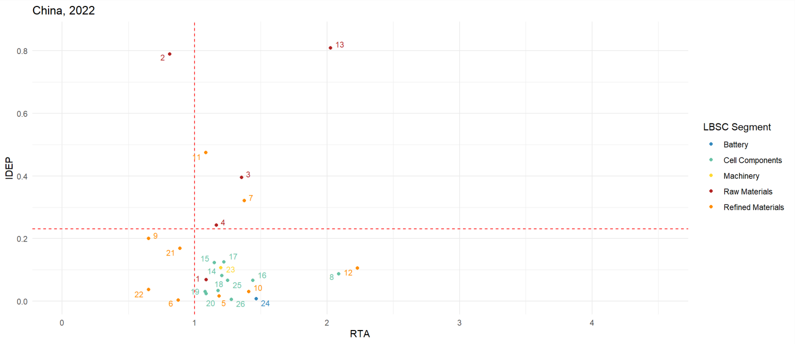
Product-level intelligence: China



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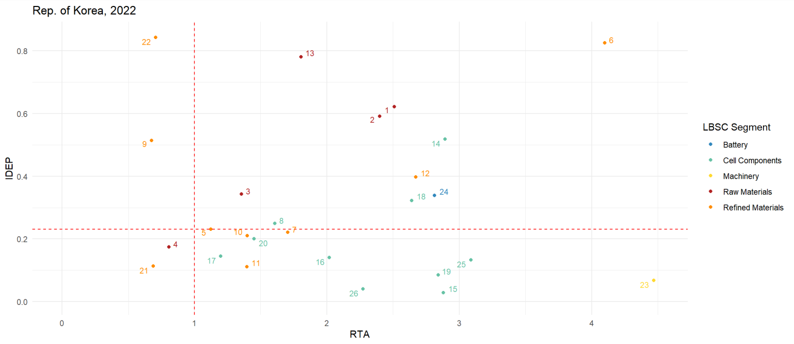
Product-level intelligence: Korea



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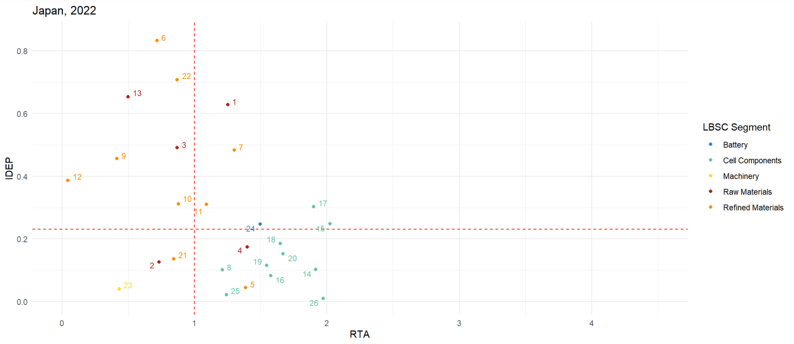
Product-level intelligence: Japan



Source: authors' elaborations on BACI and OECD REGPAT data.

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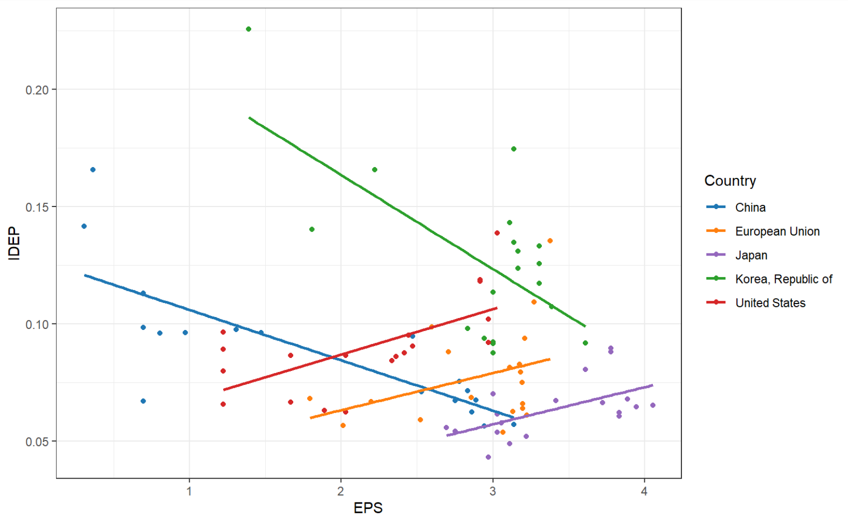
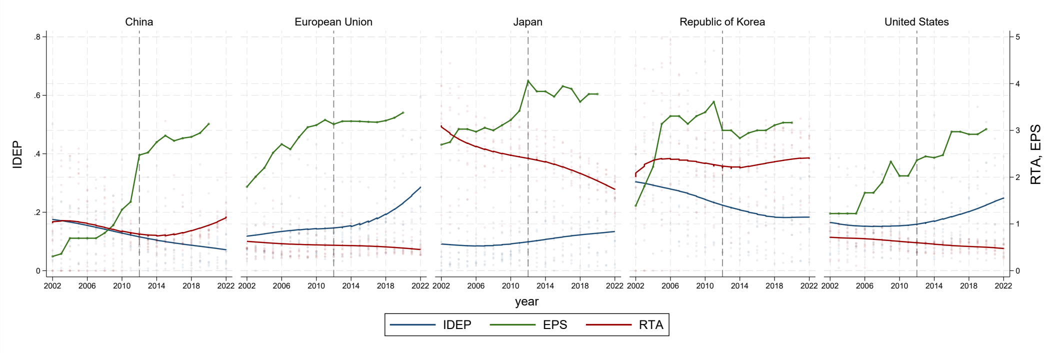
The role of Environmental Policy Stringency



The role of Environmental Policy Stringency: Downstream



Econometric estimates

Dynamic Fractional Response model

$$\text{IDEP}_{i,k,t} = \beta_0 + \rho\,\text{IDEP}_{i,k,t-1} + \beta_1\,\text{RTA}_{i,k,t-1} + \beta_2\,\text{EPS}_{i,k,t-1} + c_{i,k} + \lambda_t + \varepsilon_{i,k,t} \tag{3}$$

with $\text{IDEP}_{ikt} \in [01)$

N = 130 and T = 21

By collapsing the product level dimension, we can write: $y_{it} = \max(0,\ \rho y_{it-1} + \mathbf{x}_{it-1}\boldsymbol{\beta} + c_i + u_{it})$

- **Two-Way Fixed Effect Estimator**
  - Nickell bias is less severe with large T
  - Almost negligible mass at zero makes biasedness and consistency problem less severe
- **Random Effect Tobit** (Wooldridge, 2005; Loudermilk, 2007)

  To avoid the incidental parameter problem, we assume

  $$c_i \sim \mathcal{N}\left(\psi + \xi_0 y_{i0} + \bar{x}_i\xi,\ \sigma_a^2\right)$$

  where $a_i|y_{i0}, \bar{x}_i \sim N(0, \sigma_a^2)$ can be treated as a RE. Therefore we can use maximum likelyhood to estimate

$$\text{IDEP}_{ikt} = \theta + \rho\,\text{IDEP}_{ikt-1} + \beta_1\,\text{RTA}_{ikt-1} + \beta_2\,\text{EPS}_{it-1} + \xi_0\text{IDEP}_{ik0} + \xi_1\text{R}\bar{\text{T}}\text{A}_{i,k} + \xi_2\text{E}\bar{\text{P}}\text{S}_{i,k} + a_i + \lambda_t + \varepsilon_{ikt}. \tag{4}$$

Panel fixed Effect estimator

	Full	UP	MID	DOWN
	(1)	(2)	(3)	(4)
$IDEP_{i,k,t-1}$	0.645***	0.562***	0.654***	0.670***
	(0.0265)	(0.0726)	(0.0405)	(0.0339)
$RTA_{i,k,t-1}$	0.000974	0.00912***	0.000813	-0.00828**
	(0.000815)	(0.00235)	(0.000884)	(0.00357)
$EPS_{i,k,t-1}$	0.00341	0.0307**	-0.000882	-0.00173
	(0.00476)	(0.0115)	(0.00727)	(0.00698)
Panel FE	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes
Observations	2468	473	950	1045
Groups	130	25	50	55
Within R^2	0.426	0.408	0.448	0.454
F-statistic	41.86***	80.07***	37.83***	54.42***

Standard errors clustered at the country-product level in parentheses.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

	(1) China	(2) EU	(3) Japan	(4) Korea	(5) USA
$IDEP_{t-1}$	0.647***	0.658***	0.663***	0.662***	0.657***
	(0.0332)	(0.0345)	(0.0329)	(0.0378)	(0.0363)
RTA_{t-1}	-0.00974***	-0.00919**	-0.00756**	-0.00669*	-0.00870**
	(0.00338)	(0.00362)	(0.00337)	(0.00368)	(0.00354)
EPS_{t-1}	0.0170*	-0.0000900	-0.000794	0.00277	-0.00418
	(0.00894)	(0.00706)	(0.00706)	(0.00787)	(0.00706)
$CN*EPS_{t-1}$	-0.0221***				
	(0.00790)				
$EU*EPS_{t-1}$		0.0294***			
		(0.00822)			
$JP*EPS_{t-1}$			0.0190		
			(0.0115)		
$KR*EPS_{t-1}$				-0.0291**	
				(0.0110)	
$US*EPS_{t-1}$					0.0233***
					(0.00635)
N	1045	1045	1045	1045	1045

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Correlated Random Effects (CRE) Tobit estimator

	Full (1)	UP (2)	MID (3)	DOWN (4)
$IDEP_{i,k,t-1}$	0.749***	0.645***	0.756***	0.793***
	(0.0197)	(0.0420)	(0.0314)	(0.0328)
$RTA_{i,k,t-1}$	0.00116	0.00894***	0.00105	-0.00820**
	(0.000860)	(0.00330)	(0.000939)	(0.00367)
$EPS_{i,k,t-1}$	0.00287	0.0278***	0.000058	-0.00229
	(0.00343)	(0.00830)	(0.00560)	(0.00495)
$IDEP_{i,k,0}$	0.224***	0.291***	0.265***	0.0932***
	(0.0245)	(0.0623)	(0.0427)	(0.0243)
$\overline{RTA}_{i,k}$	-0.00187	0.00782	0.000149	0.00249
	(0.00249)	(0.0129)	(0.00303)	(0.00459)
$\overline{EPS}_{i,k}$	0.00950*	-0.00661	0.0121	0.0130**
	(0.00573)	(0.0162)	(0.00943)	(0.00650)
σ_u	0.0264***	0.0381***	0.0268***	0.00567
	(0.00299)	(0.00760)	(0.00489)	(0.00573)
Time FE	Yes	Yes	Yes	Yes
Observations	2468	473	950	1045
Groups	130	25	50	55
Log-Likelihood	3268.3	607.1	1241.6	1488.8
Chi-squared	4728.8***	677.1***	2427.2***	1974.4***

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

	(1)	(2)	(3)	(4)	(5)
	China	EU	Japan	Korea	USA
IDEP_{t-1}	0.771***	0.789***	0.795***	0.793***	0.785***
	(0.0331)	(0.0329)	(0.0323)	(0.0326)	(0.0331)
RTA_{t-1}	-0.00919**	-0.00830**	-0.00819**	-0.00819**	-0.00852**
	(0.00366)	(0.00367)	(0.00367)	(0.00367)	(0.00366)
EPS_{t-1}	0.00799	-0.00214	-0.00248	-0.00249	-0.00283
	(0.00602)	(0.00494)	(0.00495)	(0.00496)	(0.00494)
CN*EPS_{t-1}	-0.0121***				
	(0.00409)				
EU*EPS_{t-1}		0.00263			
		(0.00251)			
JP*EPS_{t-1}			-0.00346*		
			(0.00200)		
KR*EPS_{t-1}				0.00121	
				(0.00205)	
US*EPS_{t-1}					0.00534**
					(0.00253)
$IDEP_{t0}$	0.0973***	0.0941***	0.0820***	0.0891***	0.0963***
	(0.0240)	(0.0244)	(0.0237)	(0.0247)	(0.0244)
$R\bar{T}A$	0.00638	0.00546	0.00419	0.00174	0.00408
	(0.00478)	(0.00539)	(0.00462)	(0.00475)	(0.00465)
$E\bar{P}S$	-0.0104	0.00907	0.0165**	0.0132**	0.0156**
	(0.0101)	(0.00751)	(0.00675)	(0.00648)	(0.00666)
N	1045	1045	1045	1045	1045

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Findings and Policy Implications

Findings

1. LB trade shows high growth after 2020, following a rise in innovation since 2015.
2. These trends are largely driven by China and Korea, while US and EU shrink. Japan loses trade shares, but retains technological capabilities.
3. Today, China accounts for 66% of exports and 34% of filed patents. However, it shows dependency in upstream phases, which is being addressed by increasing innovation.
4. The EU and the US remain highly dependent on China concerning final batteries, but the EU retains a competitive advantage in machines that should be preserved.
5. The effect of technological specialisation on dependency is heterogeneous across LBSC stages and countries: the strongest and most significant effect is found in the downstream segment.
6. Complex EPS-dependency interplay: in China, a phased and balanced policy mix contributed to reduce dependency; in the US and EU EPS positively correlates with higher dependency.

Policy Implications

- The acceleration towards net-zero transition is compatible with strategic autonomy and economic security objectives only when environmental policies are coherently coupled with targeted industrial and innovation policies.
- Importance of developing a systematic product level strategic intelligence analysis looking at key SCs, from both the trade and technological sides, to identify areas for policy action (i.e. segments, product and technological domains).
- Need for targeted industrial and innovation policies on specific SC nodes.
- Industrial and innovation policies should aim to specialise in segments that are critical to the development of green value chains and where leadership is attainable, in order to accelerate the transition and counter-balance dependency in other nodes.
- In a polarized world marked by strong tensions the European Union must identify and strengthen specific technological and productive assets it already has at its disposal or reasonably aims to develop. Only by doing so it can secure the bargaining power needed at the negotiating tables that will define the future framework of international relations.

Thank you for the attention

Comments welcome at:

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	Full	UP	MID	DOWN
Constant	0.0515***	0.0498**	0.0651***	0.0479***
	(0.00781)	(0.0194)	(0.0132)	(0.0113)
$IDEP^{rob}_{i,k,t-1}$	0.683***	0.664***	0.688***	0.677***
	(0.0259)	(0.0397)	(0.0454)	(0.0345)
$RTA_{i,k,t-1}$	0.000375	0.00649***	0.000225	-0.00655**
	(0.000541)	(0.00142)	(0.000535)	(0.00314)
$EPS_{i,t-1}$	0.00153	0.0163**	-0.00232	0.000111
	(0.00324)	(0.00732)	(0.00548)	(0.00457)
Panel FE	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes
Observations	2468	473	950	1045
# Groups	130	25	50	55
Within R^2	0.481	0.562	0.497	0.466
F-statistic	48.79***	423.2***	37.36***	53.42***

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Fixed Effects Estimates by Stage (alternative IDEP)

	China	EU	Japan	Korea	USA
Constant	0.0357***	0.0420***	0.0396***	0.0489***	0.0490***
	(0.0125)	(0.0113)	(0.0119)	(0.0121)	(0.0116)
$IDEP^{rob}_{i,k,t-1}$	0.660***	0.669***	0.671***	0.663***	0.659***
	(0.0371)	(0.0347)	(0.0331)	(0.0366)	(0.0384)
$RTA_{i,k,t-1}$	-0.00750**	-0.00713**	-0.00606**	-0.00515	-0.00700**
	(0.00302)	(0.00321)	(0.00297)	(0.00319)	(0.00317)
$EPS_{i,t-1}$	0.0114*	0.00114	0.000821	0.00439	-0.00183
	(0.00604)	(0.00464)	(0.00460)	(0.00563)	(0.00463)
$EPS_{i,t-1} \times D_{China}$	-0.0132**				
	(0.00602)				
$EPS_{i,t-1} \times D_{EU}$		0.0175***			
		(0.00653)			
$EPS_{i,t-1} \times D_{Japan}$			0.0136		
			(0.00850)		
$EPS_{i,t-1} \times D_{Korea}$				-0.0270***	
				(0.00867)	
$EPS_{i,t-1} \times D_{USA}$					0.0196***
					(0.00538)
Panel FE	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes
Observations	1045	1045	1045	1045	1045
# Groups	55	55	55	55	55
Within R^2	0.470	0.469	0.468	0.476	0.474
F-statistic	57.79***	52.62***	56.59***	44.98***	54.63***

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Fixed Effects Regression with Country Dummies in Downstream (alternative IDEP)

	Full	UP	MID	DOWN
Constant	-0.0154	-0.00667	-0.0227	-0.00286
	(0.00976)	(0.0270)	(0.0162)	(0.0102)
$IDEP^{rob}_{i,k,t-1}$	0.788***	0.748***	0.788***	0.800***
	(0.0193)	(0.0384)	(0.0303)	(0.0327)
$RTA_{i,k,t-1}$	0.000550	0.00648***	0.000416	-0.00582**
	(0.000618)	(0.00206)	(0.000701)	(0.00270)
$EPS_{i,t-1}$	0.000985	0.0142***	-0.00131	-0.00111
	(0.00246)	(0.00518)	(0.00419)	(0.00364)
$IDEP^{rob}_{i,k,0}$	0.222***	0.220***	0.285***	0.104***
	(0.0257)	(0.0541)	(0.0454)	(0.0267)
$\overline{RTA}_{i,k}$	-0.00126	0.00163	0.000158	0.00256
	(0.00174)	(0.00812)	(0.00209)	(0.00337)
$\overline{EPS}_{i,k}$	0.00671*	-0.00356	0.00982	0.00704
	(0.00404)	(0.0101)	(0.00670)	(0.00474)
σ_u	0.0182***	0.0237***	0.0179***	0.00413
	(0.00221)	(0.00512)	(0.00353)	(0.00425)
Time FE	Yes	Yes	Yes	Yes
Observations	2468	473	950	1045
Groups	130	25	50	55
Log-Likelihood	4083.5	831.4	1520.6	1811.2
Chi-squared	6435.1***	1168.1***	3666.5***	2335.4***

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Random Effect Tobit by Stage (alternative IDEP)

	(1) China	(2) EU	(3) Japan	(4) Korea	(5) USA
Constant	0.0271*	0.000730	-0.00613	-0.00388	-0.0100
	(0.0151)	(0.0110)	(0.0106)	(0.0104)	(0.0106)
$IDEP^{rob}_{i,k,t-1}$	0.784***	0.798***	0.801***	0.799***	0.790***
	(0.0332)	(0.0329)	(0.0325)	(0.0330)	(0.0332)
$RTA_{i,k,t-1}$	-0.00653**	-0.00589**	-0.00581**	-0.00583**	-0.00614**
	(0.00270)	(0.00270)	(0.00270)	(0.00270)	(0.00269)
$EPS_{i,t-1}$	0.00564	-0.00101	-0.00121	-0.000952	-0.00151
	(0.00442)	(0.00364)	(0.00364)	(0.00365)	(0.00362)
$EPS_{i,t-1} \times D_{China}$	-0.00786***				
	(0.00289)				
$EPS_{i,t-1} \times D_{EU}$		0.00164			
		(0.00181)			
$EPS_{i,t-1} \times D_{Japan}$			-0.00156		
			(0.00154)		
$EPS_{i,t-1} \times D_{Korea}$				-0.000934	
				(0.00165)	
$EPS_{i,t-1} \times D_{USA}$					0.00466**
					(0.00190)
$IDEP^{rob}_{i,k,0}$	0.106***	0.105***	0.0959***	0.110***	0.111***
	(0.0263)	(0.0267)	(0.0269)	(0.0293)	(0.0269)
$\overline{RTA}_{i,k}$	0.00524	0.00444	0.00340	0.00308	0.00396
	(0.00351)	(0.00396)	(0.00345)	(0.00350)	(0.00342)
$\overline{EPS}_{i,k}$	-0.00831	0.00454	0.00858*	0.00695	0.00921*
	(0.00734)	(0.00548)	(0.00495)	(0.00476)	(0.00484)
σ_u	0.00444	0.00434	0.00363	0.00445	0.00453
	(0.00396)	(0.00411)	(0.00465)	(0.00411)	(0.00399)
Time FE	Yes	Yes	Yes	Yes	Yes
Observations	1045	1045	1045	1045	1045
Groups	55	55	55	55	55
Chi-squared	2411.5***	2331.2***	2415.8***	2300.6***	2412.7***

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Random effect Tobit by country in the Downstream (interaction with EPS) (alternative IDEP)

Further evidence from the photovoltaic industry

PV Supply chain 'intelligence': IDEP vs RTA (EU & US, 2019)