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From mines to markets: Gravity model insights on critical raw material trade

Frederik Stender [a], Tim Vogel [b,*]

[a] German Institute of Development and Sustainability (IDOS), Tulpenfeld 6, 53113 Bonn, Germany
[b] German Institute of Development and Sustainability (IDOS), Bonn, Germany

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ABSTRACT

Access to critical raw materials (CRMs) is increasingly shaped by geopolitical dynamics, sparking a global competition for supply security. Using the gravity model of trade, we examine how OECD countries leverage Aid for Trade (AfT), Bilateral Investment Treaties (BITs), and Preferential Trade Agreements (PTAs) to influence CRM imports from developing countries. Panel data from 1995–2023 show that while intensive-margin effects of North-South PTAs appear economically negligible in the global trade equilibrium, these agreements play a strategic role in facilitating market entry and shaping supply-chain geography. Our results underscore that a coordinated mix of trade diplomacy, investment frameworks, and targeted aid is key to resilient and diversified CRM access for OECD countries.

1. Introduction

Our modern world runs on critical raw materials (CRMs). Elements like lithium, cobalt and rare earth metals lie at the heart of high-tech innovation and the green energy transition, making CRMs a top priority on political and economic agendas worldwide (see *The Economist*, 2023). While major economies such as Australia, Canada, and especially China hold substantial reserves, large (untapped) deposits are located across low- and middle-income countries. Access to these resources, however, is often constrained by extraction challenges and geopolitical dependencies, sparking a global race to secure supply (UNCTAD, 2024; WEF, 2024).

This competition is reshaping resource geopolitics. While China remains central to CRM supply chains, others are intensifying their engagement. The EU, for instance, has incorporated dedicated measures to stabilise CRM supply in its recent trade agreements with Chile, Mexico, and Indonesia. Meanwhile, its broader Global Gateway initiative and the recently signed first Clean Trade and Investment Partnership (CTIP) with South Africa signal a shift toward more integrated financial-industrial cooperation. Similarly, through the Minerals Security Partnership (MSP), Japan, Norway, South Korea, the UK, and the U. S. are advancing investment-led strategies that mobilise public and private capital for CRM projects in developing economies.

This letter offers a macro-level empirical view of the evolving policy landscape. While many recent initiatives are too new and complex for comprehensive evaluation, we draw on historical experience to highlight factors that continue to shape current strategies. To this end, we focus on three established policy instruments – Aid for Trade (AfT), Bilateral Investment Treaties (BITs), and Preferential Trade Agreements (PTAs) – as proxies for broader and ongoing shifts in OECD (Organisation for Economic Co-operation and Development) countries' CRM engagement in imports from developing partners.

These instruments capture distinct but complementary purposes: PTAs formalise trade relations and enhance policy cooperation; BITs attract Foreign Direct Investment (FDI) and signal regulatory stability; and AfT supports infrastructure and productive capacity. Together, they form a potential policy mix for long-term supplier partnerships.

We build on recent gravity model research of critical resource trade

* Corresponding author.
E-mail addresses: frederik.stender@idos-research.de (F. Stender), tim.vogel@idos-research.de (T. Vogel).

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(e.g., Farag and Zaki, 2025; Zhong and Su, 2023) as well as sector-specific work on fuels and rare earth metals (e.g., Barnes and Bosworth, 2015; Farag and Zaki, 2023; Shigetomi et al., 2017; Yaseen et al., 2025; Zhang et al., 2018). While this literature emphasises supply- and demand-side determinants, it pays little attention to the strategic role of (bilateral) foreign policy instruments. Our analysis addresses this gap.

Section 2 outlines our empirical strategy and data, Section 3 presents results, and Section 4 concludes.

2. Empirical strategy and data

2.1. Estimation models

We examine how AfT, BITs, and PTAs affect CRM trade from multiple empirical angles. Our primary specification is an augmented gravity model estimated using the Poisson pseudo-maximum likelihood (PPML) estimator, which addresses residual heteroscedasticity and zero-trade flows (Santos Silva and Tenreyro, 2006):

$$M_{ijt} = \exp\left[\eta_{it} + \mu_{jt} + \beta_1 asinh\left(AfT_{ijt-1}\right) + \beta_2 BIT_{ijt} + \beta_3 PTA_{ijt} + \vec{\pi}_{ij} + \varepsilon_{ijt}\right] \tag{1}$$

where M_{ijt} denotes CRM imports of OECD country i from developing country j in year t, and ε_{ijt} are standard errors clustered at the country-pair level.[1] Directional country-pair ($\vec{\pi}_{ij}$) and two-way importer-year and exporter-year fixed effects (η_{it} and μ_{jt}) control for policy endogeneity, multilateral trade resistance, and other structural and country-specific determinants of CRM trade.

Following the AfT- and broader empirical trade literature, annual AfT flows (AfT_{ijt}) from i to j are transformed using the inverse hyperbolic sine to accommodate the high share (78 per cent) of zero-AfT observations in our estimation sample, reduce skewness, and preserve interpretability in a log-like framework (e.g., Fuchs et al., 2025; Kristjánsdóttir, 2012; Yoon et al., 2024).[2] AfT is lagged by one period to mitigate reverse causality. PTA_{ijt} and BIT_{ijt} are dummies equal to 1 if a country pair has a PTA or BIT in force, respectively, in year t, and 0 otherwise.[3]

To better understand the mechanics captured in the estimation of Eq. (1), we explore both trade margins. First, we focus on the intensive margin of trade by restricting the analysis to positive trade flows. Using the PPML estimator, we examine how AfT, BITs, and PTAs influence the value of *existing* trade relationships.

Second, we analyse the extensive margin of trade, that is, the formation of *new* trade links, emphasising the role of geographical diversification and strategic importance of potentially low-value CRMs. Preserving the contribution of smaller flows in the analysis, we define a binary variable coded 1 for positive trade flows, and 0 otherwise, and estimate a linear probability model (LPM) using the same set of explanatory variables as before:

$$P\left(M_{ijt} > 0\right) = \eta_{it} + \mu_{jt} + \beta_1 asinh\left(AfT_{ijt-1}\right) + \beta_2 BIT_{ijt} + \beta_3 PTA_{ijt} + \vec{\pi}_{ij} + \varepsilon_{ijt} \tag{2}$$

We choose the LPM over probit or logit models to avoid incidental-parameter bias with high-dimensional fixed effects (Greene, 2004).

2.2. Data

Our data cover 1995–2023, with 33 OECD importers and 172 developing country exporters (see Appendix Tables A1 and A2).[4] Annual CRM trade, measured in current million US dollars (USD), is aggregated at the country-pair level using Harmonised System (HS) 6-digit lines corresponding to relevant CRMs. These lines are drawn from the January 2025 version of the Base pour l'Analyse du Commerce International (BACI) database (Gaulier and Zignago, 2010) and identified following the Georgitzikis (2023) CRM classification.

This classification distinguishes base CRMs and selected intermediate products derived from them into four distinct supply chain stages: Extraction and mining, processing and refining, fabrication, and recycling. This granularity enables nuanced policy analysis, particularly since supply bottlenecks are often concentrated in processing and refining (Le Mouel and Poitiers, 2023). Moreover, unlike broader classifications that include materials like wood, the Georgitzikis (2023) list focusses on CRMs central to high-tech industries and the green energy transition. Appendix Table A3 provides a detailed list of the base CRMs and associated HS 6-digit product lines included in our analysis.

PTA (content) data are from the World Bank's Deep Trade Agreements database 2.0 (Mattoo et al., 2020), BIT data from the Electronic Database of Investment Treaties (EDIT) (Alschner et al.(2021), and AfT data in constant million USD from the OECD Creditor Reporting System (2025), using disbursements to capture realised financial flows.

Summary statistics are provided in Appendix Table A4.

3. Results

Table 1 presents baseline results for aggregated CRM trade. Columns (1)-(2) report PPML estimates including zero-trade flows (*overall* trade); columns (3)-(4) focus on positive trade flows (intensive margin); and columns (5)-(6) apply a LPM to assess the extensive margin.

Each model tests the (i) presence (columns 1, 3, 5) and the depth and complexity (columns 2, 4, 6) of PTAs and BITs. *PTA depth* measures provisions across 18 policy areas, with higher scores indicating deeper agreements.[5] *BIT complexity* reflects treatment scope across nine key categories. Both indices are normalised between 0 and 1 for comparability. Agreement coverage allows testing whether CRM trade is driven by the agreements themselves or by their scope.

Across all models, PTAs show a strong and statistically significant positive effect on CRM trade, raising both trade values and the likelihood of new supplier links.[6] These effects align with findings for total

[1] Despite recent advances in gravity modelling, data on domestic trade are not available for the specific CRM trade flows considered in this paper. Following Larch & Yotov (2024), this omission likely implies that our estimates represent a lower bound.

[2] The inverse hyperbolic sine transformation is defined as $\ln\left(x + \sqrt{(x^2+1)}\right)$, where, in our case, x is the AfT value. The transformation also allows the inclusion of negative values, which can arise from repayments of concessional loans, ex-post corrections, or end-of-project circle repayments. In practice, the number of negative AfT observations in our sample is very limited, and removing them from the estimation has a negligible effect on the results reported below.

[3] Note that we do not lag the PTA and BIT dummies, as they switch from 0 to 1 upon entry into force and remain at 1 thereafter. Unlike the year-specific AfT data, this coding reflects broader time windows and thus does not require adjustment for potential reverse causality.

[4] As importers, we include all OECD Development Assistance Committee (DAC) donors that reported AfT commitments at the start of our sample period. All current EU member states are included, given their joint trade policy. Countries classified as aid recipients in the DAC data are treated as developing countries in our analysis.

[5] Strong multicollinearity among PTA provisions generally complicates isolating their individual effects, while deeper PTAs may also proxy for CRM coverage.

[6] Note that coefficient interpretation varies by model. For instance, in the case of the PTA variable, columns (1) to (4) show the percentage change in the dependent variable for country pairs participating in a common PTA, while estimates related to the extensive margin in columns (5) and (6) reflect changes in the probability of positive CRM trade.

Table 1
Baseline results.

	Overall		Intensive margin		Extensive margin	
Dep. variable	M_{ijt}		$M_{ijt} > 0$		$P(M_{ijt} > 0)$	
	(1)	(2)	(3)	(4)	(5)	(6)
asinh(AfT)	−0.005	−0.005	−0.007	−0.006	**0.001****	**0.001****
	(−1.02)	(−0.99)	(−1.21)	(−1.19)	**(2.01)**	**(2.01)**
BIT	0.105	0.127	**0.109***	**0.133***	0.013	0.010
	(1.58)	(1.59)	**(1.67)**	**(1.69)**	(1.62)	(1.08)
PTA	**0.204***	**0.186***	**0.201***	**0.176***	**0.029***	**0.049***
	(2.91)	**(1.73)**	**(2.91)**	**(1.65)**	**(3.30)**	**(3.64)**
BIT complexity		−0.090		−0.100		0.011
		(−0.45)		(−0.51)		(0.54)
PTA depth		0.073		0.107		**−0.115****
		(0.20)		(0.29)		**(−2.29)**
Observations	118,454	118,454	61,562	61,562	157,696	157,696
Country pairs	4,380	4,380	3,810	3,810	5,632	5,632
Estimator	PPML	PPML	PPML	PPML	FE OLS	FE OLS

Notes: Robust, clustered (at the country-pair level) standard errors in parentheses. Asterisks denote the level of statistical significance with *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Constant, country-pair and country-year fixed effects always included but not reported.

Table 2
PTA effect using different estimation samples.

	'$OECD_i xglobal_j$' sample			'Fully global' sample		
	Overall	Intensive	Extensive	Overall	Intensive	Extensive
	(1)	(2)	(3)	(4)	(5)	(6)
PTA^{NS}	**0.141****	**0.132***	**0.025***	−0.082	−0.088	**0.035***
	(1.98)	**(1.86)**	**(2.89)**	(−0.99)	(−1.07)	**(6.60)**
PTA^{Other}	**0.295***	**0.295***	0.000	**0.169***	**0.172***	**0.021***
	(3.24)	**(3.25)**	(0.05)	**(3.03)**	**(3.10)**	**(6.00)**
Observations	162,729	96,408	219,504	738,380	346,334	1330,055
Country pairs	5,910	5,213	7,592	26,727	22,198	46,122
Estimator	PPML	PPML	FE OLS	PPML	PPML	FE OLS

Notes: Robust, clustered (at the country-pair level) standard errors in parentheses. Asterisks denote the level of statistical significance with *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. All regressions include group-specific AfT and BIT policy variables, a constant, country-pair and country-year fixed effects (not reported).

trade (see Larch and Yotov, 2024) but likely stem from factors beyond tariff cuts, as Most Favoured Nation (MFN) tariffs on CRMs are already near zero in most major economies (own calculation based on data from World Bank, 2025). PTAs instead may promote trade by locking in these low tariffs, enhancing policy transparency and predictability, and providing a signal of political commitment. Many recent PTAs also reduce export restrictions (see Korinek and Bartos, 2012), building trust and reliability, especially along the extensive margin.[7]

BITs and AfT exhibit weaker and more nuanced effects. BITs appear to sustain existing trade links but have limited influence on the formation of new ones, possibly reflecting investors' preference for established partners. AfT supports new trade links by improving infrastructure and productive capacity but shows little impact on expanding existing flows – perhaps because earlier AfT rounds already unlocked extensive-margin gains, leaving diminishing returns at the intensive margin.[8]

These findings remain robust when accounting for PTA depth and BIT complexity. Notably, BIT complexity has no measurable effect on CRM trade, consistent with evidence that more stringent BIT design features have limited effects on FDI (Berger et al., 2011). While deeper PTAs may even dampen new supplier formation (column 6), this result should be interpreted with caution, as PTA depth can vary with the constellation of integration partners (e.g., by level of development). The observed pattern may therefore reflect agreement-specific dynamics rather than generalisable effects of PTA depth.[9]

While our baseline focuses on a restricted sample of OECD importers and developing-country exporters, thereby capturing conditional effects within that group, structural gravity theory emphasises modelling trade within a fully global system to properly account for multilateral

[7] Our baseline findings are robust to various alternative specifications. These include reallocating EU institutional aid to member states based on their national contributions to the EU budget; treating the EU as a single donor by aggregating EU institutional and member state AfT; using longer AfT lags; excluding OECD countries with substantial own CRM exports; limiting the exporter sample to major CRM exporters; excluding China entirely due to its role as a dominant global CRM hub; varying the sample period (for example, starting in 2002 or ending in 2019); and disaggregating AfT by type. Also, some CRMs might be traded at substantially higher values than others. To ensure that the dependent variable is not driven by a small number of high-value observations, we exclude the upper 25^{th} and 50^{th} percentiles of HS 6-digit line observations from our sample prior to aggregating into a single annual measure for each country pair. These alternative trimming thresholds do not significantly affect the results reported.

[8] As securing CRMs is a (rather) recent political priority, we have also tested for time variation in policy effects but found no significant differences (available upon request).

[9] While country-pair fixed effects account for endogeneity in PTA and BIT formation, our policy variables could still capture other temporal shifts in bilateral trade. For example, the U.S. Inflation Reduction Act offered tax credits for domestic battery production only if critical minerals were sourced from U.S. or PTA partners (Bastida et al., 2023). To ensure that our estimates are not biased by such effects, we conducted placebo tests on *overall* trade based on our baseline sample, using annual PTA dummies dated prior and after agreement implementation. We find no significant effects in the pre-implementation period, while positive effects emerge only once the PTA enters into force. This pattern supports the interpretation that our results capture genuine PTA-driven effects rather than unrelated policy shocks (see Appendix Figure A1).

Table 3
Policy interaction results.

Dep. variable	Overall M_{ijt} (1)	Intensive $M_{ijt} > 0$ (2)	Extensive $P(M_{ijt} > 0)$ (3)
asinh(AfT)	−0.0027	−0.0049	**0.0024***
	(−0.35)	(−0.65)	**(2.80)**
BIT	0.0336	0.0316	**0.0200****
	(0.40)	(0.39)	**(2.29)**
PTA	**0.4184***	**0.3929***	**0.0403***
	(4.47)	**(4.21)**	**(4.31)**
asinh(AfT) ∗ BIT	**0.0172***	**0.0174***	−0.0009
	(1.85)	**(1.88)**	(−0.73)
asinh(AfT) ∗PTA	**−0.0321***	**−0.0293***	**−0.0036***
	(−4.01)	**(−3.71)**	**(−2.94)**
BIT ∗PTA	−0.0338	−0.0220	−0.0179
	(−0.37)	(−0.24)	(−1.64)
Observations	118,454	61,562	157,696
Country pairs	4,380	3,810	5,632
Estimator	PPML	PPML	FE OLS

Notes: Robust, clustered (at the country-pair level) standard errors in parentheses. Asterisks denote the level of statistical significance with *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Constant, country-pair and country-year fixed effects always included but not reported.

resistance (Larch et al., 2025).

Building on this, Table 2 re-estimates the three reduced-form specifications from Table 1 (i.e., excluding BIT complexity and PTA depth) using two broader samples: First, we expand the exporter set to 230 trading partners while retaining OECD importers (columns 1–3). Second, we estimate the models on a fully global sample including all bilateral flows among 230 trading partners (columns 4–6). Given the central role of PTAs in our baseline results, we focus on PTA effects (full results are available upon request).

The positive extensive-margin effect for a PTA between an OECD importer and a developing-country exporter (PTA^{NS}) remains robust under sample expansion. By contrast, the intensive-margin effect declines and becomes insignificant in the fully global sample, also weakening relative to PTAs between other importer-exporter pairs (PTA^{Other}). This attenuation suggests that part of the effect observed in the restricted sample reflected incomplete control for multilateral resistance.

From a policy perspective, this distinction matters. These results do not imply that North-South PTAs are unimportant. Rather, once global interdependencies are fully internalised, their conditional intensive-margin effect appears economically negligible. Meanwhile, the robust extensive-margin effect underscores the strategic role of formal trade agreements in facilitating market entry and shaping supply-chain geography.

Our paper does not examine PTAs in isolation. Instead, we adopt a broader perspective on the policy instruments used by OECD countries to secure access to CRMs. Within this framework, we further exploit the restricted sample to more directly examine patterns of OECD-developing country CRM trade, including the role of AfT. Because AfT is institutionally limited to North-South relations, this restricted-sample setting is commonly adopted in the AfT gravity literature (e.g., Hoekman et al., 2023; Hoekman and Shingal, 2020; Nowak-Lehmann et al., 2013), allowing meaningful comparison of our findings with related studies.

First, leading economies increasingly combine trade diplomacy, investment policies, and financial and technical support measures – often as part of broader trade and development strategies, whether coherently structured or not. Table 3 therefore examines how these policy instruments interact. AfT and PTAs exhibit a negative interaction, suggesting that the (conditional) positive effects of PTAs diminish when paired with AfT. This may reflect overlapping objectives – such as streamlining export procedures – resulting in redundancy and diminishing returns when both are scaled simultaneously.

Conversely, AfT and BITs show complementarity, possibly because AfT strengthens supply-side capacity, while BITs enhance investor confidence and mobilise capital to exploit these improvements.

The interaction between BITs and PTAs remain statistically insignificant, consistent with Heid and Vozzo (2020) for overall trade.

Second, Table 4 explores heterogeneity along the CRM value chain. While the regressions offer a fragmented picture, a notable pattern is that PTAs are most strongly associated with downstream fabrication trade, whereas BITs are linked to upstream mining but also in circular-economy segments such as recycling.

This distinction carries important implications: PTAs appear to have limited influence on trade in unprocessed CRMs directly after extraction.

Table 4
Results by supply chain stage.

	Extraction and mining			**Processing and refining**		
	Overall (1)	**Intensive (2)**	**Extensive (3)**	**Overall (4)**	**Intensive (5)**	**Extensive (6)**
asinh(AfT)	0.014	0.013	**0.002****	**−0.016****	**−0.017****	0.001
	(1.41)	(1.26)	**(2.57)**	**(−2.29)**	**(−2.48)**	(1.62)
BIT	**0.211***	**0.225****	**0.029***	−0.137	**−0.138***	**0.018****
	(1.87)	**(2.07)**	**(3.59)**	(−1.64)	**(−1.66)**	**(2.26)**
PTA	0.043	0.037	0.014	−0.001	−0.002	0.014
	(0.38)	(0.32)	(1.49)	(−0.01)	(−0.02)	(1.59)
Observations	93,367	58,535	157,696	92,824	58,643	157,696
Country pairs	3,578	3,350	5,632	3,595	3,338	5,632
Estimator	PPML	PPML	FE OLS	PPML	PPML	FE OLS
	Fabrication			**Recycling**		
	Overall (7)	**Intensive (8)**	**Extensive (9)**	**Overall (10)**	**Intensive (11)**	**Extensive (12)**
asinh(AfT)	−0.013	−0.013	**0.001***	0.009	0.009	0.000
	(−1.31)	(−1.31)	**(1.99)**	(0.84)	(0.82)	(0.51)
BIT	0.026	0.025	**0.028***	**0.236****	**0.235****	**0.034***
	(0.29)	(0.29)	**(3.71)**	**(2.50)**	**(2.49)**	**(4.22)**
PTA	**0.185***	**0.185***	0.002	−0.121	−0.122	0.004
	(1.74)	**(1.74)**	(0.30)	(−0.93)	(−0.94)	(0.48)
Observations	93,130	57,682	157,696	88,739	57,372	157,696
Country pairs	3,655	3,334	5,632	3,385	3,179	5,632
Estimator	PPML	PPML	FE OLS	PPML	PPML	FE OLS

Notes: Robust, clustered (at the country-pair level) standard errors in parentheses. Asterisks denote the level of statistical significance with *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Constant, country-pair and country-year fixed effects always included but not reported.

However, in the specific OECD-developing country setting, they may play a role in supporting value addition within developing countries by encouraging some domestic fabrication before export – be this due to gaps in OECD manufacturing capacities, or deliberate efforts to promote deeper supply chain integration. PTAs could thus contribute to local content generation and broader industrial development.

Conversely, BITs tend to facilitate investment in sectors characterised by high capital intensity and long investment horizons, where strategic importance might offset these financial risks. These findings underscore the complementary roles of PTAs and BITs in shaping different parts of the CRM value chain.

4. Conclusions

Understanding how foreign policy tools affect CRM trade is crucial for both high-income and developing countries. For advanced economies, secure CRM access underpins industrial competitiveness and economic security. For developing countries, trade, aid and investment frameworks can facilitate entry into global value chains.

Our results indicate that, although the intensive-margin effects of North-South PTAs appear economically negligible in the global trade equilibrium, these agreements play a strategic role in facilitating market entry and shaping supply-chain geography. Focussing on a sample of OECD importers and developing-country exporters, BITs seem to primarily reinforce existing relationships, while AfT supports the formation of new trade links. At the sectoral level, PTAs' link to downstream processing points to their potential to foster local value addition and broader industrial development.

These findings highlight the importance of a coordinated mix of trade diplomacy, investment frameworks, and targeted aid to ensure resilient and diversified CRM access for OECD countries. Durable, rules-based frameworks – anchored in PTAs and complemented by targeted aid and investment agreements – offer a balanced path toward supply security and cooperation with developing partners.

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Declaration of AI use in the writing process

During the writing process, the authors used ChatGPT solely for language refinement of the final draft of the manuscript before submission, and thoroughly reviewed and edited all content.

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Appendix

Table A1, A2, A3, A4, Fig. A1

Table A1
Exporting countries in the baseline sample.

Afghanistan	Ghana	Palau
Albania	Grenada	Palestine
Algeria	Guatemala	Panama
Angola	Guinea	Papua New Guinea
Anguilla	Guinea-Bissau	Paraguay
Antigua and Barbuda	Guyana	Peru
Argentina	Haiti	Philippines
Armenia	Honduras	Rwanda
Aruba	Hong Kong	Saint Helena, Asc. and Tr. da C.
Azerbaijan	India	Saint Kitts and Nevis
Bahamas	Indonesia	Saint Lucia
Bahrain	Iran	Saint Vincent and the Grenadines
Bangladesh	Iraq	Samoa
Barbados	Israel	Sao Tome and Principe
Belarus	Jamaica	Saudi Arabia
Belize	Jordan	Senegal
Benin	Kazakhstan	Serbia
Bermuda	Kenya	Seychelles
Bhutan	Kiribati	Sierra Leone
Bolivia	Korea, Democratic People's Republic of	Singapore
Bosnia and Herzegovina	Korea, Republic of	Sint Maarten
Botswana	Kyrgyzstan	Slovenia
Brazil	Lao People's Democratic Republic	Solomon Islands
Burkina Faso	Lebanon	Somalia
Burundi	Lesotho	South Africa
Cabo Verde	Liberia	South Sudan
Cambodia	Libya	Sri Lanka
Cameroon	Macao	Sudan
Cayman Islands	Madagascar	Suriname
Central African Republic	Malawi	Syrian Arab Republic

(*continued on next page*)

Table A1 (*continued*)

Afghanistan	Ghana	Palau
Chad	Malaysia	Tajikistan
Chile	Maldives	Tanzania
China	Mali	Thailand
Colombia	Malta	Timor-Leste
Comoros	Marshall Islands	Togo
Congo	Mauritania	Tokelau
Cook Islands	Mauritius	Tonga
Costa Rica	Mayotte	Trinidad and Tobago
Côte d'Ivoire	Mexico	Tunisia
Croatia	Micronesia	Turkey
Cuba	Moldova	Turkmenistan
Cyprus	Mongolia	Turks and Caicos Islands
Democratic Republic of Congo	Montenegro	Tuvalu
Djibouti	Montserrat	Uganda
Dominica	Morocco	Ukraine
Dominican Republic	Mozambique	United Arab Emirates
Ecuador	Myanmar	Uruguay
Egypt	Namibia	Uzbekistan
El Salvador	Nauru	Vanuatu
Equatorial Guinea	Nepal	Venezuela
Eritrea	New Caledonia	Viet Nam
Eswatini	Nicaragua	Virgin Islands
Ethiopia	Niger	Wallis and Futuna
Fiji	Nigeria	Yemen
French Polynesia	Niue	Zambia
Gabon	North Macedonia	Zimbabwe
Gambia	Oman	
Georgia	Pakistan	

Table A2
Importing countries in the baseline sample.

Australia	Denmark	Ireland	Netherlands	Spain
Austria	Estonia	Italy	Norway	Sweden
Belgium	Finland	Japan	Poland	Switzerland
Bulgaria	France	Latvia	Portugal	United Kingdom
Canada	Germany	Lithuania	Romania	United States
Croatia	Greece	Luxembourg	Slovakia	
Czech Republic	Hungary	Malta	Slovenia	

Table A3
List of base critical raw materials used for computation of dependent variable.

Raw material	Associated HS-6-digit lines
Aluminium	260600, 262040, 281810, 281820, 281830, 282690, 282732, 282749, 283322, 283330, 284990, 285000, 285100, 380290, 382390, 760110, 760120, 760200, 760310, 760320, 760410, 760421, 760429, 760511, 760519, 760521, 760529, 760611, 760612, 760691, 760692, 760711, 760719, 760720, 760810, 760820, 760900
Antimony	261710, 262090, 282580, 282619, 282690, 282739, 282749, 283090, 284190, 285100, 382390, 780191, 780199, 800120, 811000
Arsenic	253090, 262090, 280480, 281119, 281129, 281210, 281290, 281390, 285000, 285100, 780199
Baryte	251110, 280519, 281630, 282619, 282690, 282739, 282919, 283090, 283327, 283429, 283660, 284190, 284990
Beryllium	261790, 262090, 282590, 282619, 283429, 740329, 740500, 740829, 740990, 741129, 811211, 811219
Bismuth	260700, 260900, 261790, 262020, 262090, 282590, 282749, 283429, 283699, 284190, 284290, 780199, 810600
Boron	252890, 280450, 281000, 281290, 282690, 284011, 284019, 284020, 284030, 284990, 285000, 293100, 720299
Cerium	280530, 284610, 360690, 381590
Cobalt	260500, 282200, 282540, 282739, 283090, 283329, 283429, 283699, 285100, 291529, 291711, 382390, 750110, 810510, 810590
Coking coal	270112, 270400
Copper	260300, 260700, 260800, 261610, 261690, 262019, 262020, 262030, 282550, 282690, 282739, 282741, 283090, 283325, 283429, 283719, 284290, 285100, 740110, 740200, 740311, 740312, 740313, 740319, 740321, 740322, 740329, 740400, 740500, 740610, 740620, 740710, 740721, 740729, 740811, 740819, 740821, 740822, 740829, 740911, 740919, 740921, 740929, 740931, 740939, 740940, 740990, 741011, 741012, 741021, 741022, 741110, 741121, 741122, 741129, 741210, 741220, 750110
Dysprosium	280530, 284690, 720299
Erbium	280530, 284690
Europium	280530, 284690
Feldspar	250590, 252910, 252930, 700100

(*continued on next page*)

Table A3 (*continued*)

Raw material	Associated HS-6-digit lines
Fluorspar	252921, 252922, 253090, 280130, 281111, 281119, 281290, 282612, 282619, 282630, 282690, 390469
Gadolinium	280530, 284690
Gallium	260600, 282590, 282739, 284290, 285000, 285100, 293100, 811291, 811299
Germanium	260800, 261790, 282560, 282690, 282739, 284190, 284290, 285000, 285100, 381590, 381800, 811291, 811299
Hafnium	261510, 282560, 282590, 282739, 285000, 293100, 382390, 810910, 810990, 811291, 811299
Helium	271111, 271121, 280429
Holmium	280530, 284690
Iridium	261690, 262090, 284310, 284390, 711041, 711049
Lanthanum	280530, 284690, 381590
Lithium	253090, 280519, 282520, 282619, 282690, 282739, 282759, 282990, 283691, 382390
Lutetium	280530, 284690
Magnesium	251810, 293100, 310490, 810411, 810419, 810420, 810430, 810490
Manganese	253090, 260200, 261900, 282010, 282090, 282739, 283329, 283330, 284160, 284990, 285000, 285100, 293100, 382390, 720130, 720211, 720219, 720230, 811100
Natural graphite	250410, 250490, 380120, 380190, 382330, 382390, 400520, 400591, 400599, 681390
Neodymium	280530, 284690, 720299
Nickel	260400, 262090, 282540, 282735, 283090, 283324, 283429, 283719, 285100, 382390, 720130, 720260, 720421, 721810, 721890, 740329, 740822, 740940, 741122, 750110, 750120, 750210, 750220, 750300, 750400, 750511, 750512, 750521, 750522, 750610, 750620, 750711, 750712, 750720, 810590, 811220
Niobium	261590, 262090, 282590, 282619, 282690, 284190, 284990, 285000, 382330, 720293, 811291, 811299
Palladium	261690, 262090, 284310, 284390, 711021, 711029, 711290
Phosphate rock	251010, 251020, 262100, 280920, 283510, 283522, 283524, 283525, 283526, 283529, 283531, 283539, 310100, 310310, 310390, 310510, 310520, 310530, 310540, 310551, 310559, 310560
Phosphorus	251010, 251020, 280470, 280910, 280920, 281210, 281290, 281390, 285100, 293100, 720299
Platinum	261690, 262090, 284310, 284390, 382390, 711011, 711019, 711290
Praseodymium	280530, 284690
Rare earth elements	253090, 382390
Rhodium	261690, 262090, 284310, 284390, 711031, 711039
Ruthenium	261690, 262090, 284310, 284390, 711041, 711049
Samarium	280530, 284690
Scandium	280530, 284690
Silicon metal	250610, 250621, 280461, 280469, 281210, 281390, 284920, 285000, 285100, 293100
Strontium	253090, 280519, 281630, 282919, 283090, 283329, 283429, 283692, 284190
Tantalum	261590, 262090, 282590, 282690, 282739, 284190, 284990, 285000, 382330, 720293, 720299, 810310, 810390
Tellurium	282590
Terbium	280530, 284690
Thulium	280530, 284690
Titanium metal	261400, 720291, 810810, 810890
Tungsten	261100, 262090, 282590, 282619, 282739, 284180, 284990, 285000, 381590, 382330, 382390, 720280, 810110, 810191, 810193, 810199, 810590
Vanadium	261210, 261590, 261900, 262090, 282530, 282739, 282749, 283329, 284190, 284990, 285000, 720292, 811291, 811299
Ytterbium	280530, 284690
Yttrium	280530, 284690

Note: Classification follows Georgitzikis (2023).

Table A4
Summary statistics for the baseline sample.

	Obs.	Mean	Standard Deviation	Min.	Max.
M (imports [intensive margin])	157,696	25,166	264,363	0	16,344,856
M (import dummy [extensive margin]))	157,696	0.40	0.49	0	1
M (mining imports)	157,696	12,856	207,015	0	16,331,429
M (processed imports)	157,696	9,801	115,368	0	7,861,460
M (fabricated imports)	157,696	3,476	48,605	0	4,390,963
M (recycled imports)	157,696	2,089	30,215	0	3,318,267
AfT	157,696	1,985	25,582	−18,309	3,395,840
PTA	157,696	0.22	0.41	0	1
PTA depth (non-normalised)	157,696	221.41	538.14	0	3,466
PTA depth	157,696	0.04	0.10	0	0.67
BIT	157,696	0.20	0.40	0	1
BIT complexity (non-normalised)	157,696	12.66	24.37	0	150
BIT complexity	157,696	0.08	0.16	0	1

Notes: CRM trade is measured in current million USD, except for the extensive margin; AfT data are in constant million USD.

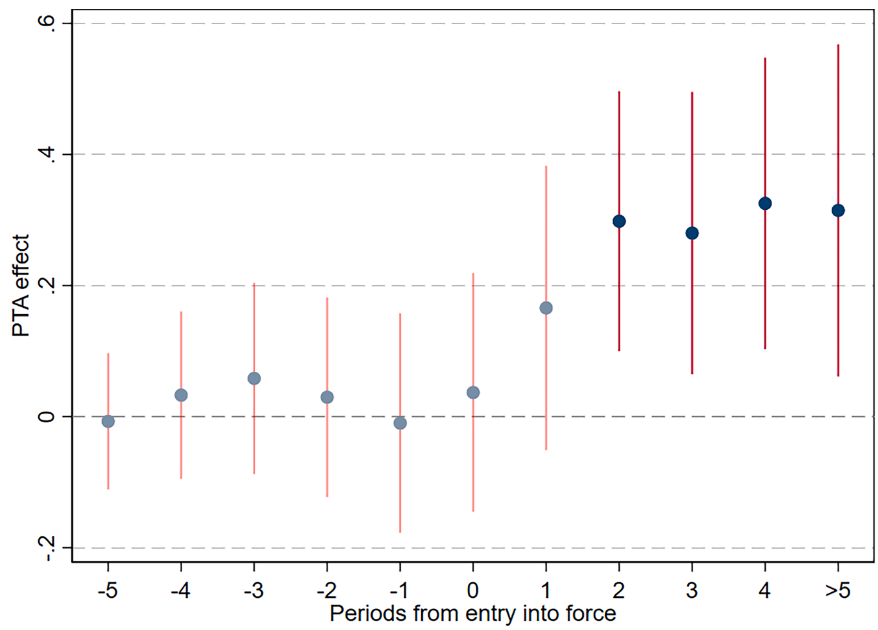

Fig. A1. PTA effect over time.
Notes: Dots denote coefficient estimates and spikes their 90 percent confidence intervals. Confidence intervals crossing zero (horizontal dashed line) indicate statistically insignificant effects. Statistically significant effects are shown in solid shades and insignificant effects in light shades. Estimation conducted using a PPML model that includes zero-trade flows, annual PTA dummies and all other variables specified in Eq. (1), based on the baseline sample.

Data availability

Data will be made available on request.

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