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# Bilateral asymmetric dependence and partner country trade network resilience: empirical evidence from China's rare earth trade

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**Background:** Against the backdrop of intensifying competition for critical mineral security, rare earth trade has become a crucial window for observing supply chain restructuring and great power rivalry.
**Methods:** Drawing on the 2013–2024 UN Comtrade data on rare earth full-industry-chain trade, this article measures the structural trade network resilience of China's rare earth trading partners at the partner country level, and examines the impact of China's bilateral asymmetric dependence on its trading partners on their trade network resilience within a two-way fixed effects framework.
**Results:** The results show that upstream export dependence asymmetry is significantly negatively associated with partner country resilience, and that this negative association operates mainly through the structural stability and diversification dimensions, remaining robust under endogeneity treatments such as system GMM. The moderating-effect and heterogeneity analyses indicate that the negative association is more pronounced among partner countries with stronger resource endowments and weaker manufacturing bases, and that partner countries with lower income levels and higher trade openness are likewise more vulnerable. Further analysis shows that midstream and downstream import dependence is not significantly associated with resilience, and that no significant reverse association is found.
**Discussion:** This article contributes to understanding the consequences of dependence in strategic mineral trade and its boundary conditions from the partner country perspective.

KEYWORDS
asymmetric dependence, industrial structure, partner country trade network resilience, rare earth trade, resource endowment

## 1 Introduction

Rare earth elements are essential inputs for new energy, electronic information, aerospace, and defense industries, and their stable supply is no longer merely a matter of resource allocation but is directly tied to industrial chain security, technological competition, and supply assurance (U.S. Geological Survey, 2025; Zhao et al., 2025; Salim et al., 2022). From the perspective of the global division of labor, China not only possesses a relatively complete rare earth industrial chain but also maintains clear advantages in key segments such as smelting and

separation, material preparation, and permanent magnet applications, and has long occupied a pivotal position in the global rare earth industrial chain (Mancheri et al., 2019). Against this backdrop, rare earth trade has moved beyond the mere cross-border flow of resources and has increasingly become a critical window for observing strategic mineral security, industrial competition, and geo-economic relations (Kalantzakos, 2020).

In recent years, global critical mineral governance has shifted markedly from an efficiency orientation to a security orientation (Leonelli, 2025; Rao et al., 2024). On the one hand, China's rare earth governance is transitioning from administrative control toward legalization, institutionalization, and whole-chain regulation (Li, 2025; Woods, 2025); on the other hand, major economies, exemplified by the U.S. Minerals Security Partnership (MSP) and the European Union's Critical Raw Materials Act (CRMA), have been strengthening policy coordination and alliance-building around critical mineral supply security, alternative source development, and supply chain restructuring (Vivoda, 2023). In this context, a more pressing question is how China's bilateral dependence structure with respect to specific trading partners affects those partners' performance in the broader trade network. This question matters because a partner country's dependence on China is not confined to individual transactions or a single market; it may also shape the partner's degree of market diversification, the scope of its external trade linkages, and its supply stability. Particularly following the enforcement of the Export Control Law and the acceleration of alternative sourcing by major economies, whether such bilateral dependence may weaken partner country trade network resilience has become a key entry point for understanding the changing landscape of rare earth trade.

This article seeks to answer three interrelated questions. First, does China's asymmetric dependence on specific trading partners affect those partners' trade network resilience? Second, through which segments of the industrial chain is this effect primarily transmitted? Third, do resource endowment and partner countries' industrial structure alter this effect? Although existing research has separately addressed critical mineral supply security, trade network resilience, and asymmetric dependence, a direct connection among the three remains underdeveloped. The literature has focused primarily on the unilateral impact of Chinese rare earth policies on supply chain resilience (Mancheri et al., 2019), the macro-level mapping of cross-border flows of critical materials (Liu et al., 2022), and the identification of bilateral dependence and competition structures within rare earth trade networks (Xu et al., 2024). However, insufficient attention has been paid to whether bilateral asymmetric dependence between China and its trading partners affects those partners' trade network resilience, and under what conditions this effect is strengthened or weakened. Without clarifying this issue, it is difficult to accurately gauge the actual scope of China's rare earth trade influence or to assess the role of resource endowment and external coordination factors.

Against this background, this article takes the bilateral relations between China and its rare earth trading partners over 2013–2024 as the research object. It measures the trade network resilience of China's rare earth trading partners at the partner country level, constructs the upstream export dependence asymmetry of China relative to specific trading partners, and further examines the moderating effects of resource endowment and partner countries' industrial structure. The article makes three main contributions. First, it extends the analytical object of asymmetric dependence from bilateral trade flows to partner country trade network resilience, examining the impact of China's rare earth trade position on the network resilience performance of its trading partners, thereby advancing research on dependence in strategic mineral trade to the level of partner country network consequences. Second, it incorporates resource endowment and partner countries' industrial structure within a unified analytical framework, identifying the boundary conditions of asymmetric dependence effects. Third, it clearly distinguishes three levels of analysis, namely, the overall network, partner country trade network resilience, and bilateral asymmetric dependence, and maintains consistency in variable definitions and formula expressions, thereby strengthening the correspondence among the research object, analytical perspective, and indicator construction.

## 2 Literature review

### 2.1 Asymmetric dependence and structural power

The power-dependence theory proposed by Emerson (1962) holds that power in exchange relations derives from the imbalance in the degree of mutual dependence between parties. Baldwin (1980) further argues that interdependence does not necessarily imply power parity; what truly determines the distribution of power is the differential in exit costs, substitutability, and the resulting cost-sensitivity asymmetries. Building on this proposition, international trade scholarship has applied the concept of asymmetric dependence to explain trade constraints, technological lock-in, and value chain bargaining. Dallas et al. (2019) classify power in global value chains into four forms, namely, bargaining, demonstrative, institutional, and constitutive power, and reveal the mechanisms through which dependence asymmetry is converted into structural power. Farrell and Newman (2019) point out that states positioned at key nodes in global networks can exert coercion on dependent actors through information surveillance and access restriction. Yang et al. (2025) analyze the ICT supply chain and find that asymmetric dependence significantly affects a country's technological autonomy and supply stability. Buldyrev et al. (2010) demonstrate that a single point of failure in interdependent networks can trigger systemic collapse through cascading propagation, while Gao et al. (2016) find that the resilience of complex networks follows universal patterns, with local dependence relations being amplified into global consequences through network topology. Nevertheless, existing research has largely centered on how asymmetric dependence affects bilateral trade gains, policy bargaining, and a country's structural power within global value chains, while the question of how it shapes the resilience performance of specific trading partners in the broader trade network, particularly in the domain of strategic mineral trade, remains underexplored with limited direct empirical evidence.

### 2.2 Trade network resilience and its measurement

Complex network analysis provides a powerful toolkit for characterizing the capacity of trade systems to maintain structural integrity and functional continuity under shocks. Ioannidis et al. (2025) employ graph theory and network science methods to reveal the shock propagation mechanisms in international trade, demonstrating that the US–China trade bipolarity has rendered the global trade network a

deep oligopoly. In the critical minerals domain, Ma et al. (2022) and Yu et al. (2023) analyze the global nickel trade network from the perspectives of topological stability and a three-dimensional resilience framework, respectively; Hao et al. (2023) and Li et al. (2024) examine the robustness and risk contagion of the lithium and cobalt trade systems through cascading failure simulations and multilayer network models; and Jiang et al. (2025) further reveal, through the case of graphite, the mechanisms by which critical material trade drives global value chain restructuring. With respect to rare earths, Mancheri et al. (2019) examine the impact of Chinese policies on rare earth supply chain resilience; Hsu et al. (2024) map the cross-border flows and circular economy potential of rare earth elements in permanent magnets; and Xu et al. (2026) reassess global rare earth market trade patterns and risk contagion from a multilayer network perspective. However, existing studies have largely centered on the overall network, single-product networks, or the supply security of individual countries, and have rarely taken the network performance of a partner country following its integration into bilateral trade relations with China as an independent object of observation; the distinction between structural network resilience and post-shock recovery resilience is also insufficiently clear. Accordingly, this article defines partner country trade network resilience as a structural resilience indicator based on annual trade structures, emphasizing that it captures the partner country's latent shock-absorbing capacity in terms of external linkage diversification, linkage expansion, and structural stability.

## 2.3 Rare earth industry chain governance and policy evaluation

As critical mineral issues have become increasingly securitized, research on rare earth industry governance and policy evaluation has grown substantially. Zuo et al. (2022), Hamed et al. (2024), and Ghorbani et al. (2025) have provided extensive discussions on the global industrial chain landscape and trade network evolution, overseas supply diversification pathways, and critical material supply chain bottlenecks. Yu et al. (2021) systematically evaluate the supply risk of China's strategic metallic minerals using a multi-criteria decision-making approach; Guo and You (2023) comparatively analyze the international competitiveness of the rare earth industries in China, Australia, Russia, and India; Runganga et al. (2025) examine the policy discourses and governance tool selection of the United States, the European Union, South Africa, and Australia through a game-theoretic framework; and Logozar (2026) further reveals, from a supply chain structural constraint perspective, how midstream processing bottlenecks, investment barriers, and ecosystem lock-in jointly give rise to supply vulnerability. At the policy level, Zhang (2026) examines the policy logic of China's rare earth export controls as they shift from resource-driven to institutionalized governance; Han et al. (2025) use a global simulation model to analyze how geopolitical actions drive the regionalization and fragmentation of rare earth trade networks; Depraiter et al. (2025) empirically document, based on Chinese export data, the association between geopolitical risk and the global supply of rare earth permanent magnets; Rizos et al. (2024) identify, through expert interviews across the full value chain, the policy, economic, and technological barriers to rare earth permanent magnet recycling; and Shen et al. (2020) systematically trace the evolution of China's public policies on rare earths from 1975 to 2018. Taken together, these studies suggest that the impact of rare earth policies extends beyond changes in export volumes or prices, and may affect broader supply chain structures through expectations, alternative sourcing, and network reconfiguration. Yet existing research has largely treated supply security, policy instruments, and resilience outcomes in isolation, without identifying, within a unified framework, the interactions among bilateral dependence structures, resource endowment, and partner countries' industrial structure.

## 2.4 Research gaps

In summary, existing research provides an important foundation for this article, yet insufficient attention has been paid to how asymmetric dependence shapes partner country trade network resilience and how this effect is moderated by resource endowment and industrial structure. Building on this gap, this article takes China's rare earth trading partners as the research object. Drawing on the 2013–2024 UN Comtrade data on rare earth full-industry-chain trade, it measures partner country trade network resilience, tests the impact of bilateral asymmetric dependence, and further examines the moderating effects of resource endowment and industrial structure, seeking to establish a tighter empirical analytical framework linking strategic mineral security, trade network resilience, and power-dependence theory.

# 3 Theoretical analysis and research hypotheses

Before proceeding to the mechanism analysis, it is necessary to clarify the analytical object of this article. The partner country trade network resilience discussed here refers to the ability of a partner country, having formed stable bilateral rare earth trade ties with China, to maintain channel diversification, linkage expansion, and transaction structure stability within the broader trade network. Accordingly, trade diversification, network connectivity, and structural stability are all structural resilience attributes at the partner country level, rather than properties of the global rare earth trade network as a whole. The core explanatory variable, upstream export dependence asymmetry, captures China's structural advantage over a specific trading partner in the bilateral relationship. Thus, what this article focuses on is not the stability of any individual bilateral trade link in itself, but the configuration of the partner country's external economic and trade relations shaped by its ties with China, and the resulting network consequences.

## 3.1 The direct effect of asymmetric dependence on partner country trade network resilience

Power-dependence theory holds that power in exchange relations is not simply determined by transaction volume, but primarily depends on the difference in the degree of dependence and substitutability between the two parties (Emerson, 1962; Baldwin, 1980). In rare earth trade, this logic has a solid industrial chain foundation. The findings of Shuai et al. (2022) show that China has long maintained significant comparative advantages in midstream and downstream segments such as smelting and separation, material preparation, and permanent magnet applications. From a global value chain governance perspective, core countries positioned at critical segments can influence upstream and downstream resource allocation through

organizational capabilities, standard setting, and market coordination (Gereffi et al., 2005). Therefore, for most trading partners, forming strong bilateral ties with China implies not only dependence on a single market, but also access to an industrial collaboration system spanning raw materials, processing, and applications.

Furthermore, relational network research emphasizes that the effects of economic ties tend to propagate along relational structures and network positions, rather than remaining confined to the strength or weakness of individual transactions (Granovetter, 1985). Martin and Sunley (2015) likewise argue that economic resilience must be understood beyond the level of single actors and examined within broader relational structures and spatial networks. Under this condition, the impact of asymmetric dependence on partner country trade network resilience hinges not on whether the bilateral link itself is stable, but on whether the partner country adjusts its external trade relationship configurations after forming strong ties with China. First, China's core position in the global rare earth industrial chain concentrates the partner country's rare earth trade toward China, making it easier for the partner country to contract its linkages with other marginal trading partners as dependence deepens, thereby reducing the number of trading partners and lowering network connectivity. Second, as the partner country tilts its limited trade resources toward China, what is crowded out is mainly small-scale marginal trade relationships, so that the remaining trade relationships become more balanced and structural stability rises. Third, because what is crowded out is mostly small trade relationships, the overall degree of dispersion of the partner country's export markets changes little. Hence, asymmetric dependence reflects not merely a generic dependency relationship, but the contracting effect of bilateral asymmetric dependence on the breadth of the partner country's trade linkages, under the condition that China maintains its core position in the global rare earth industrial chain. Accordingly, the following hypothesis is proposed:

> H1: Asymmetric dependence is significantly negatively associated with the trade network resilience of China's rare earth trading partners.

## 3.2 The moderating effect of resource endowment

The strength of the above negative association depends on the trading partner's own resource endowment. In the rare earth industrial chain, partners with stronger resource endowments are mostly located in upstream segments and specialize in the extraction and export of rare earth ores and primary products (Shuai et al., 2022; Guo and You, 2023). Since China is the world's largest processor and demander of rare earth ores, the rare earth exports of such partners are highly concentrated in the Chinese market, and their rare earth trade linkages are already relatively narrow. When their dependence on China deepens further, their limited rare earth trade resources are more readily absorbed by the Chinese core node, so that other marginal trade relationships are crowded out more markedly and the negative association becomes stronger.

From the perspective of adjustment mechanisms, although partners with stronger resource endowments possess potential autonomous supply space, their rare earth trade structure has become path-locked around ore exports to China, so their diversification and substitution capacity is in fact limited. Once such partners form dependence on China's rare earth processing system, the tendency for their trade linkages to concentrate toward China is further reinforced, and the negative association strengthens. In contrast, partners with weaker resource endowments mostly import processed rare earth products, their rare earth trade sources are relatively diversified, and they have greater room to adjust their dependence on a single core node, so the negative association is relatively weaker. Accordingly, the following hypothesis is proposed:

> H2: The stronger a trading partner's resource endowment, the stronger the negative association between asymmetric dependence and the trade network resilience of China's rare earth trading partners.

## 3.3 The moderating effect of industrial structure

The strength of the above negative association likewise depends on the trading partner's own industrial structure. Baldwin (1980) emphasizes that power depends not only on the degree of dependence but also on exit costs and substitutability: if the dependent party can quickly turn to alternative sources or domestic production after a shock, its vulnerability diminishes accordingly. In the rare earth industrial chain, the manufacturing base is an important indicator of a partner's substitution capacity. Partner countries with weaker manufacturing bases lack both the capacity to process and transform imported rare earth intermediate products and the ability to absorb external dependence through industrial structure adjustment; when their asymmetric dependence on China deepens, the tendency for their trade linkages to concentrate toward China is harder to reverse, and the negative association is therefore stronger.

From the perspective of adjustment mechanisms, partners with weaker manufacturing bases are mostly positioned at primary processing or direct import segments in the rare earth industrial chain, their domestic industries have limited capacity to absorb rare earth intermediate products, and they lack substitution and adjustment room in the face of China's supply advantages. In contrast, partners with stronger manufacturing bases possess the potential for processing, transformation, and substitute production, enabling them to adjust their trade relationship configurations more quickly and reduce dependence on China as a single node, so the negative association is relatively weaker. Accordingly, the following hypothesis is proposed:

> H3: The weaker a trading partner's manufacturing base, the stronger the negative association between asymmetric dependence and the trade network resilience of China's rare earth trading partners.

# 4 Research design

## 4.1 Sample coverage and data sources

This article selects 2013–2024 as the research period and takes the countries and regions that have engaged in rare earth trade with China worldwide as the observation objects. Given that the article focuses on the bilateral asymmetric dependence between China and its trading

partners and its network consequences, the sample unit is set as the partner country–year, and China itself is not included as an explained object in the regression. Through this treatment, the article retains the structural information of the global rare earth trade network while grounding the analysis in partner country level differences and their changes.

Rare earth trade data are primarily sourced from the United Nations UN Comtrade database. Following the approach of Liu et al. (2025) and based on HS six-digit codes, this article selects four product categories to capture rare earth trade across the full industrial chain: 253090 (rare earth ores), 284690 (rare earth compounds), 280530 (rare earth metals), and 850511 (rare earth permanent magnets). Among them, upstream refers to the extraction and initial beneficiation of rare earth ores (253090), midstream refers to smelting and separation and material preparation (280530, 284690), and downstream refers to permanent magnet manufacturing and end-use applications (850511); this upstream–midstream–downstream industrial chain division is consistent with the relevant rare earth supply chain literature (Mancheri et al., 2019; Shuai et al., 2022). Meanwhile, considering that the main downstream applications of rare earth permanent magnets are concentrated in integrated circuits and laser equipment (both of which use large amounts of neodymium–iron–boron magnets in production), this article incorporates 8542 (integrated circuits) and 9013 (lasers) into the rare earth trade network as downstream applications, so as to more completely capture the network position of partner countries across the rare earth full industrial chain. It should be noted that these two categories are not used in the measurement of dependence asymmetry: trade network resilience aims to reflect the overall network position of a partner country across the rare earth full industrial chain, so incorporating downstream applications helps to fully characterize its network linkages; whereas dependence asymmetry aims to characterize the dependence relations of rare earth products themselves, and downstream applications do not belong to the rare earth product category, so they are not included. Bilateral trade flows are based on China's reported data; individual missing trade values are treated as zero, and observations for which dependence asymmetry cannot be calculated are dropped.

On this basis, the article constructs annual rare earth trade networks by taking countries and regions as nodes and bilateral rare earth trade values as directed weighted edges, and then calculates resilience indicators at the partner country level. It should be particularly noted that partner country trade network resilience can be measured across a broad sample of China's trading partners, with the network sample covering 917 partner country–year observations; however, upstream export dependence asymmetry requires that the flow of rare earth ores imported by China from a partner country be positive, and not all network partner countries engage in upstream ore trade with China. Therefore, the observations entering the baseline regression shrink from 917 in the network sample to 587, of which the balanced panel with observations in all twelve consecutive years contains 340. In other words, the network sample covered by descriptive statistics does not fully coincide with the core sample entering the upstream export dependence asymmetry regression, and the effective observations in regressions for specific dimensions also vary depending on data availability. Control variable data are mainly sourced from the World Bank WDI database. It should be noted that, because the financial development index is available only through 2021 and therefore has substantial missing values, it is excluded from the control variables, leaving the remaining seven control variables.

## 4.2 Variable description

### 4.2.1 Dependent variable: partner country trade network resilience (TNR)

The formulas for the variables and the regression models used in this study are presented in Equation 1–14. The TNR measured in this article does not represent the overall resilience of the global rare earth trade network. Rather, it refers to the capacity of a trading partner, while maintaining bilateral trade ties with China, to sustain channel diversification, linkage expansion, and transaction structure stability in the broader trade network. Strictly speaking, since this article uses indicators based on annual trade network structures rather than recovery path data following specific shocks, TNR is closer at the operational level to the structural network resilience among the dimensions of partner country trade network resilience. This article constructs a composite index of partner country trade network resilience from three dimensions: trade diversification, network connectivity, and structural stability. The three dimensions draw, respectively, on the Herfindahl–Hirschman Index in trade diversification and concentration measurement (Imbs and Wacziarg, 2003; Cadot et al., 2011), the node degree in network science (Newman, 2010), and the Gini coefficient (Gini, 1921; Cadot et al., 2011), and, following the resilience framework of Wu et al. (2025), aggregate the three into a composite index through min-max normalization and entropy weighting. Larger values indicate stronger trade network resilience of the partner country.

(1) Trade Diversification (Div). Div measures the degree of dispersion of a trading partner's export markets, reflecting its capacity to adjust toward other markets while maintaining trade ties with China. This article uses the adjusted Herfindahl–Hirschman Index as a reverse indicator:

$$\mathrm{Div}_{it} = 1 - \sum_k \left( \frac{X_{itk}}{\sum_k X_{itk}} \right)^2 \tag{1}$$

Where $X_{itk}$ denotes the rare earth export value from partner country $i$ to destination $k$ in period $t$. A larger Div value indicates that the partner country's export destinations are more dispersed, making it easier to adjust through alternative channels when a single market fluctuates or is disrupted.

(2) Network Connectivity (Conn). Conn measures the breadth of a trading partner's connections in the annual rare earth trade network, reflecting its capacity to extend ties to other nodes on the basis of its bilateral trade relationship with China. It is expressed as the number of countries and regions that have rare earth export relations with partner country $i$:

$$\mathrm{Conn}_{it} = N_{it} \tag{2}$$

Where $N_{it}$ is the number of effective trade connections of partner country $i$ in period $t$. A larger $\mathrm{Conn}_{it}$ value indicates richer external

linkages in the network and greater scope for reallocating trade flows across different nodes.

(3) Structural Stability (Stab). Stab measures the degree of balance in the distribution of a trading partner's external trade flows across different nodes, reflecting the capacity of the trade structure to remain stable under localized shocks. This article uses the reverse indicator of the Gini coefficient of export value distribution:

$$\text{Stab}_{it} = 1 - \text{Gini}_{it} \tag{3}$$

Where $\text{Gini}_{it}$ denotes the Gini coefficient of the distribution of export values from partner country $i$ to each of its trading partners in period $t$. A larger $\text{Stab}_{it}$ value indicates a more balanced distribution of trade flows, weaker overconcentration on a few nodes, and a lower probability that localized shocks trigger systemic instability.

### 4.2.2 Core explanatory variable: upstream export dependence asymmetry (CD)

CD captures China's structural advantage over a specific trading partner in the upstream rare earth ore segment, measuring the relative gap between the partner country's export dependence on China and China's import dependence on that partner (Emerson, 1962; Baldwin, 1980), that is, the degree of asymmetry between the partner country's dependence of its ore sales on China and China's dependence of its ore supply on that partner. A larger CD value indicates that China's structural advantage in upstream resource organization and source substitution is more pronounced. Meanwhile, to examine the heterogeneity of asymmetric dependence across industrial chain segments, this article further constructs midstream technological dependence asymmetry (TD) and downstream market dependence asymmetry (MD) for dimension-wise testing.

To maintain consistency with the regressions for specific dimensions, this article uniformly defines the three subindicators as relative dependence.

(1) Upstream export dependence asymmetry ($\text{CD}_{it}$)

The upstream segment quantifies the difference between the partner country's export dependence on China's ore market and China's import dependence on that partner's ore supply. It is defined as:

$$\text{CD}_{it} = \text{DEP_exp}_{it} - \text{DEP_imp}_{it} \tag{4}$$

When $\text{CD}_{it} > 0$, the export dependence of partner country $i$ on the Chinese market is relatively stronger, while China's dependence on the ore supply of that partner is relatively weaker, giving China a more pronounced structural advantage in upstream resource organization and source substitution. When $\text{CD}_{it} < 0$, China's dependence on the ore supply of partner country $i$ exceeds the export dependence of that partner on the Chinese market. When $\text{CD}_{it} = 0$, the two sides are perfectly symmetric in their dependence, with no asymmetry.

$$\text{DEP_exp}_{it} = \frac{X^{\text{ore}}_{\text{CN}\leftarrow i,t}}{\sum_k X^{\text{ore}}_{k\leftarrow i,t}} \tag{5}$$

Where the superscript ore denotes calculations based on rare earth ores (HS253090); $\text{DEP_exp}_{it}$ is the export dependence of partner country $i$ on China's rare earth ore market in period $t$, measured as the share of ore exports to China in its total ore exports; $\text{DEP_exp}_{it} \in (0, 1)$, with larger values indicating that the rare earth ore (HS253090) sales of country $i$ are highly dependent on China; $X^{\text{ore}}_{\text{CN}\leftarrow i,t}$ is the amount of rare earth ore exported by partner country $i$ to China in year $t$, and $\sum_k X^{\text{ore}}_{k\leftarrow i,t}$ is the total amount of rare earth ore exported by partner country $i$ to all trading countries $k$ worldwide in year $t$.

$$\text{DEP_imp}_{it} = \frac{M^{\text{ore}}_{\text{CN}\leftarrow i,t}}{\sum_j M^{\text{ore}}_{\text{CN}\leftarrow j,t}} \tag{6}$$

Where $\text{DEP_imp}_{it}$ is China's import dependence on the ore supply of partner country $i$ in period $t$, measured as the share of ore imports from that partner in China's total ore imports. $\text{DEP_imp}_{it} \in (0, 1)$, with larger values indicating that China's upstream rare earth resource supply is highly dependent on that partner country, implying high resource supply risk. $M^{\text{ore}}_{\text{CN}\leftarrow i,t}$ is the amount of rare earth ore imported by China from partner country $i$ in year $t$; $\sum_j M^{\text{ore}}_{\text{CN}\leftarrow j,t}$ is the total amount of rare earth ore imported by China from all source countries j worldwide in year t.

(2) Midstream technological dependence asymmetry ($\text{TD}_{it}$)

The midstream segment quantifies the difference between the partner country's dependence on China's midstream rare earth processing system and China's dependence on that partner's midstream products. It is defined as:

$$\text{TD}_{it} = \text{DEP_mid}_{it} - \text{DEP_mid_china}_{it} \tag{7}$$

When $\text{TD}_{it} > 0$, the dependence of partner country $i$ on China's midstream processing system is relatively stronger, while China's dependence on the midstream products of that partner is relatively weaker, giving China a more pronounced structural advantage in smelting and separation, material preparation and technology transformation. When $\text{TD}_{it} < 0$, China's dependence on the midstream products of partner country i exceeds the dependence of that partner on China's rare earth midstream. When $\text{TD}_{it} = 0$, the two sides' dependence is perfectly symmetric, with no asymmetry.

$$\text{DEP_mid}_{it} = \frac{M^{\text{mid}}_{i\leftarrow \text{CN},t}}{\sum_j M^{\text{mid}}_{i\leftarrow j,t}} \tag{8}$$

Where the superscript mid denotes calculations based on two product categories, midstream rare earth metals (HS280530) and rare earth compounds (HS284690); $\text{DEP_mid}_{it}$ is the import dependence

of partner country $i$ on China's midstream rare earth products in period $t$, meaning the partner relies on Chinese midstream supply. $\mathrm{DEP_mid}_{it} \in (0, 1)$, with larger values indicating that country $i$ is more reliant on China's midstream rare earth production capacity; $M^{\mathrm{mid}}_{i\leftarrow \mathrm{CN},t}$ is the value of midstream rare earth processed products imported by country $i$ from China in period $t$, and $\sum_j M^{\mathrm{mid}}_{i\leftarrow j,t}$ is the total value of midstream rare earth processed products imported by country $i$ from all countries $j$ worldwide in period $t$.

$$\mathrm{DEP_mid_china}_{it} = \frac{M^{\mathrm{high}}_{\mathrm{CN}\leftarrow i,t}}{\sum_j M^{\mathrm{high}}_{\mathrm{CN}\leftarrow j,t}} \tag{9}$$

Where $\mathrm{DEP_mid_china}_{it}$ is China's import dependence on the midstream products of partner country i in period t, measured as the share of midstream product imports from that partner in China's total midstream product imports. $\mathrm{DEP_mid_china}_{it} \in (0, 1)$, with larger values indicating that China is more dependent on the midstream product supply of that partner country. $M^{\mathrm{mid}}_{\mathrm{CN}\leftarrow i,t}$ is the value of midstream products imported by China from partner country i in year t; $\sum_j M^{\mathrm{mid}}_{\mathrm{CN}\leftarrow j,t}$ is the total value of midstream products imported by China from all countries j worldwide in year t.

(3) Downstream market dependence asymmetry ($\mathrm{MD}_{it}$)

The downstream segment quantifies the difference between the partner country's import dependence on China's downstream rare earth processed products and China's export dependence on that partner's downstream market. It is defined accordingly:

$$\mathrm{MD}_{it} = \mathrm{DEP_down}_{it} - \mathrm{DEP_mkt}_{it} \tag{10}$$

Where $\mathrm{MD}_{it} > 0$, the partner country's import dependence on China's downstream rare earth processed products exceeds China's export dependence on that partner's market, giving China a more pronounced structural advantage in downstream product supply and market bargaining. $\mathrm{MD}_{it} < 0$, China's dependence on the partner country's market exceeds that country's dependence on Chinese products. $\mathrm{MD}_{it} = 0$, the two sides' dependence is perfectly symmetric, with no asymmetry in the downstream industrial chain.

$$\mathrm{DEP_down}_{it} = \frac{X^{\mathrm{down}}_{i\leftarrow \mathrm{CN},t}}{\sum_j X^{\mathrm{down}}_{i\leftarrow j,t}} \tag{11}$$

Where the superscript down denotes calculations based on downstream rare earth permanent magnets (HS850511); $\mathrm{DEP_down}_{it}$ is the import dependence of partner country $i$ on China's supply of downstream products such as rare earth permanent magnets in period $t$, meaning the partner relies on Chinese downstream supply, measured as the share of downstream products imported from China in the country's total imports of such products; $\mathrm{DEP_down}_{it} \in (0, 1)$, representing the share of Chinese products in the total downstream rare earth imports of country $i$. Higher values indicate that the downstream rare earth finished product supply of country $i$ is highly dependent on China. $X^{\mathrm{down}}_{i\leftarrow \mathrm{CN},t}$ is the value of downstream rare earth finished products imported by country $i$ from China in year $t$; $\sum_j X^{\mathrm{down}}_{i\leftarrow j,t}$ is the total value of downstream rare earth products imported by country $i$ from all countries $j$ worldwide in year $t$.

$$\mathrm{DEP_mkt}_{it} = \frac{X^{\mathrm{down}}_{\mathrm{CN}\rightarrow i,t}}{\sum_k X^{\mathrm{down}}_{\mathrm{CN}\rightarrow k,t}} \tag{12}$$

Where $\mathrm{DEP_mkt}_{it}$ is China's export dependence on the downstream market of partner country $i$ in period $t$, meaning China relies on that partner's market to absorb its production capacity, measured as the share of China's downstream product exports to partner country $i$ in China's total exports of such products. $\mathrm{DEP_mkt}_{it} \in (0, 1)$, representing the share of China's total downstream rare earth exports that flows to the market of country $i$. Higher values indicate that China's downstream rare earth production capacity is highly dependent on the market of country i for absorption, making China more vulnerable to the market policies and demand fluctuations of that country. $X^{\mathrm{down}}_{\mathrm{CN}\rightarrow i,t}$ is the value of downstream rare earth finished products exported by China to country $i$ in year $t$; $\sum_k X^{\mathrm{down}}_{\mathrm{CN}\rightarrow k,t}$ is the total value of downstream rare earth products exported by China to all trading countries $k$ worldwide in year $t$.

It should be noted that the above relative dependence measures require both the relevant numerator and denominator to be positive. Therefore, only partner country–year observations for which the corresponding bilateral trade flows are nonzero and the denominators are calculable can enter the measurement of $\mathrm{CD}_{it}$, $\mathrm{TD}_{it}$ and $\mathrm{MD}_{it}$. This is a key reason why the effective observations entering the upstream export dependence asymmetry measurement and the baseline regression are substantially fewer than the network observations used to construct the partner country trade network resilience indicator; the sample size for regressions on specific dimensions also varies depending on the availability of each indicator and the control variables. Accordingly, the subsequent sections report the effective observations for different indicators separately in the descriptive statistics and the regression results.

### 4.2.3 Moderating variables

This article sets two moderating variables. The first is the resource endowment variable (resource_rents), measured by the share of resource rents in GDP from the World Bank World Development Indicators (WDI) database, which is used to identify whether the trading partner's resource endowment alters the relationship between asymmetric dependence and trade network resilience. The second is the industrial structure variable, measured by the share of manufacturing value added in GDP, which is used to characterize the partner country's processing, transformation, and substitution adjustment capacity.

### 4.2.4 Control variables

To reduce omitted variable bias, this article selects a set of country-level control variables and uniformly applies a one-period lag to all of them. Specifically, they include: the logarithm of per capita GDP (ln_gdppc), measuring the level of economic development; the logarithm of population (ln_pop), measuring market size; trade openness (trade_open), measured as total trade as a percentage of GDP, reflecting the degree to which a country is integrated into the global trading

system; net foreign direct investment inflows as a share of GDP (fdi_inflow), reflecting the degree of international capital participation; government final consumption expenditure as a share of GDP (gov_consume), reflecting the size of government and the extent of government intervention; internet penetration (internet_users), reflecting the level of information technology development; and manufacturing value added as a share of GDP (manuf_value_added), reflecting the manufacturing base and the potential demand for rare earth raw materials.

## 4.3 Model specification

To test the direct effect of asymmetric dependence on partner country trade network resilience, the following baseline regression model is constructed:

$$\mathrm{TNR}_{it} = \alpha + \beta \mathrm{CD}_{it} + \gamma \mathrm{Controls}_{it-1} + \mu_i + \lambda_t + \varepsilon_{it} \quad (13)$$

Where $\mathrm{TNR}_{it}$ is the trade network resilience of partner country $i$ in year $t$; $\mathrm{CD}_{it}$ is the upstream export dependence asymmetry of partner country $i$ in year $t$; $\mathrm{Controls}_{it-1}$ denotes the vector of control variables lagged by one period; $\mu_i$ is the country fixed effect controlling for time-invariant country heterogeneity; $\lambda_t$ is the year fixed effect controlling for common time trends and macro shocks; $\varepsilon_{it}$ is the random error term. A significantly negative $\beta$ indicates that, after controlling for country heterogeneity and annual shocks, stronger bilateral asymmetric dependence is associated with lower partner country resilience.

To test the moderating effects of resource endowment and industrial structure, interaction terms are added to the baseline model, yielding the extended model:

$$\begin{aligned}\mathrm{TNR}_{it} = {} & \alpha + \beta_1 \mathrm{ASI}_{it} + \beta_2 \left(\mathrm{ASI}_{it} \times \mathrm{resource}_{\mathrm{rentsit}}\right) \\ & + \beta_3 \left(\mathrm{ASI}_{it} \times \mathrm{G7}_i\right) + \gamma \mathrm{Controls}_{it-1} + \mu_i + \lambda_t + \varepsilon_{it}\end{aligned} \quad (14)$$

Where $\beta_2$ identifies the impact of resource endowment on the marginal effect of CD; a significantly negative value indicates that stronger resource endowment amplifies the negative association between asymmetric dependence and partner country trade network resilience. $\beta_3$ identifies whether industrial structure alters the marginal effect of CD; a significantly negative value indicates that a weaker industrial structure amplifies the contracting effect of asymmetric dependence on partner country resilience. Based on the results of the Hausman test, this article adopts a two-way fixed effects model for estimation and clusters standard errors at the partner country level.

# 5 Empirical results and analysis

## 5.1 Stylized facts and descriptive statistics

Before proceeding to the regression analysis, this article first describes the basic characteristics of the sample through the lens of the rare earth trade network structure. Figure 1 presents the global rare earth trade network structure for 2013 and 2024. At both time points, China is located at the core of the network and maintains a clear advantage in the scale of its connections. Compared with 2013, although the overall network size contracted somewhat in 2024, the core linkages centered on China did not weaken noticeably; instead, the clustering patterns among trading partners became more distinct. This suggests that, over the sample period, global rare earth trade did not break free from dependence on core nodes, but rather exhibited more pronounced structural differentiation amid supply chain adjustments. The boundaries between the Asia-centered trade group organized around China and the transatlantic trade group centered on Europe, the United States and Japan have become clearer, and this community differentiation roughly corresponds, in an intuitive sense, to the geopolitical camps

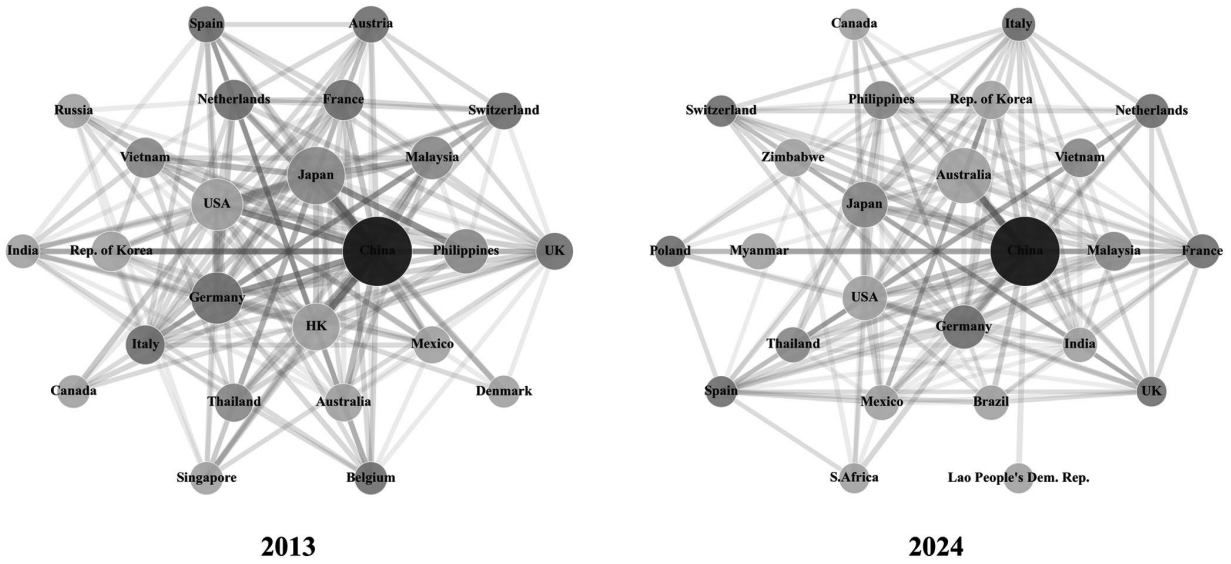


FIGURE 1
Global rare earth trade network topology. Node colors are assigned by the Louvain community detection algorithm. The network exhibits clear community differentiation, and the well-defined community structure roughly corresponds, in an intuitive sense, to the geopolitical camps of major economies. It should be noted that this interpretation is based only on the intuitive presentation of network topology and is not the conclusion of a formal statistical test.

TABLE 1 Descriptive statistics of main variables.

| Variable | Obs | Mean | Std.dev. | Min | Median | Max |
|---|---|---|---|---|---|---|
| TNR | 917 | 0.361 | 0.133 | 0.062 | 0.349 | 0.656 |
| Div | 917 | 0.656 | 0.282 | 0.000 | 0.777 | 0.954 |
| Conn | 917 | 61.382 | 52.005 | 1.000 | 53.000 | 193.000 |
| Stab | 917 | 0.301 | 0.282 | 0.020 | 0.170 | 1.000 |
| CD | 820 | 0.223 | 0.312 | 0.000 | 0.058 | 1.000 |
| TD | 466 | 0.355 | 0.314 | −0.769 | 0.304 | 1.000 |
| MD | 873 | 0.510 | 0.250 | 0.006 | 0.533 | 1.000 |
| ln_gdppc | 781 | 9.946 | 1.104 | 6.943 | 10.303 | 11.802 |
| ln_pop | 782 | 16.881 | 1.441 | 10.936 | 16.786 | 21.095 |
| trade_open | 759 | 89.867 | 52.442 | 17.831 | 75.388 | 367.042 |
| fdi_inflow | 780 | 4.360 | 26.398 | −296.013 | 2.493 | 431.788 |
| gov_consume | 734 | 17.029 | 5.255 | 4.809 | 17.532 | 42.412 |
| Internet | 779 | 66.914 | 28.230 | 1.150 | 78.418 | 100.000 |
| Manufacturing | 766 | 13.825 | 5.305 | 1.697 | 12.831 | 37.098 |

TABLE 2 Baseline regression of the impact of upstream export dependence on trade network resilience.

| Variable | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| CD | −0.057* (0.032) | −0.084*** (0.028) | | |
| TD | | | 0.006 (0.011) | |
| MD | | | | 0.014 (0.025) |
| Control variables | Yes | Yes | Yes | Yes |
| Country fixed effects | Yes | Yes | Yes | Yes |
| Year fixed effects | Yes | Yes | Yes | Yes |
| Observations | 587 | 340 | 356 | 619 |
| $R^2$ | 0.059 | 0.221 | 0.095 | 0.019 |

The full-sample baseline regression has 587 observations, and the balanced-panel baseline regression has 340 observations, the latter using core partners observed in all twelve consecutive years as the sample. Clustered robust standard errors at the country level in parentheses. ***, ** and * denote significance at the 1%, 5% and 10% levels, respectively.

of major economies; however, this interpretation is based only on the intuitive presentation of network topology and is not a causal or statistical inference about geopolitical divergence. For this article, this implies that China still possesses the necessary conditions to shape the external trade relationship configurations of its partner countries, and it also provides the empirical backdrop for testing H1 in the subsequent analysis.

Table 1 reports the descriptive statistics of the main variables. This article operates with two layers of observation: the trade network sample and the core regression sample. The former is used to construct the partner country trade network resilience indicator, covering 120 trading partner countries and 917 partner country–year observations over the period from 2013 to 2024; the latter requires the simultaneous availability of the upstream export dependence asymmetry and the control variables, and therefore contains relatively fewer effective observations. Consequently, the effective observations for variables such as TNR, Div, Conn, Stab and CD, TD are not identical, and all baseline regressions reported below use the overlapping sample as the benchmark.

In terms of the overall distribution, the mean of TNR is 0.361 with a standard deviation of 0.133, indicating notable differences in the trade network resilience of different partner countries at different time points. Across the three constituent dimensions, the mean of trade diversification (Div) is 0.656, the mean of network connectivity (Conn) is 61.382, and the mean of structural stability (Stab) is 0.301. Among them, Conn has the largest standard deviation, suggesting that differences in the breadth of external linkages across partner countries are an important source of resilience heterogeneity. The mean of the core explanatory variable upstream export dependence asymmetry (CD) is 0.287, indicating that for the majority of partner countries, China's bilateral structural advantage is not pronounced and that strong asymmetric dependence is mainly concentrated among a small number of core partners.

## 5.2 Baseline regression

Table 2 reports the baseline regression results. Column (1) estimates with the full sample; after controlling for country fixed effects and year fixed effects, the estimated coefficient of upstream export dependence asymmetry (CD) is −0.053, significantly negative at the 10 percent level. Column (2) further estimates with the balanced panel of countries observed in all twelve consecutive years, and the coefficient of CD is −0.084, significant at the 1 percent level. This indicates that the more pronounced

TABLE 3 The impact of upstream export dependence on each dimension of trade network resilience.

| Variable | (1) Div (diversification) | (2) Conn (connectivity) | (3) Stab (stability) |
|---|---|---|---|
| CD | −0.157* (0.090) | 2.791 (2.068) | −0.106** (0.046) |
| Control variables | Yes | Yes | Yes |
| Country fixed effects | Yes | Yes | Yes |
| Year fixed effects | Yes | Yes | Yes |
| Observations | 587 | 587 | 587 |
| $R^2$ | 0.055 | 0.044 | 0.034 |

***, ** and * denote significance at the 1%, 5% and 10% levels, respectively.

China's structural advantage over a trading partner in the upstream rare earth ore segment, the lower the partner country's trade network resilience, thus supporting H1. Taken together with the preceding theoretical analysis, this implies that the effect of upstream export dependence is not confined to the bilateral China–partner link itself, but is further reflected in the partner country's channel diversification and structural stability within the broader trade network. Columns (3) and (4) report the dimension-wise results for midstream technological dependence asymmetry (TD) and downstream market dependence asymmetry (MD), respectively; both coefficients are positive and insignificant, indicating that the negative association of asymmetric dependence is not uniformly distributed across the full industrial chain but is mainly concentrated in the upstream export dependence segment, and that midstream and downstream import dependence do not significantly weaken partner country resilience.

## 5.3 Dimension-wise regression

Table 3 reports the dimension-wise regression results after decomposing trade network resilience into the three dimensions of diversification, connectivity, and structural stability. The results show that the coefficient of upstream export dependence asymmetry (CD) on structural stability is −0.106 and significant at the 5 percent level, the coefficient on diversification is −0.157 and significant at the 10 percent level, and the coefficient on connectivity is insignificant. This indicates that the negative association of upstream export dependence is driven mainly by the two dimensions of structural stability and diversification: the deeper a partner country's dependence on ore exports to China, the more unbalanced its trade flow distribution and the more concentrated its export markets, and the lower its structural network resilience. It should be noted that the dimension-wise regression can only show that the negative association is more prominent in the structural stability and diversification dimensions; as to whether the underlying mechanism is the crowding out of specific trade relationships, the dimension-wise regression alone is insufficient to provide direct evidence, and this article does not make an overly strong mechanism inference.

## 5.4 Robustness tests

To test the robustness of the baseline findings, this article conducts checks across three dimensions: sample treatment, variable treatment, and data reporting. The results are reported in Table 4. In terms of sample treatment, Column (1) excludes the year 2020, a special year of the COVID-19 pandemic and the entry into force of the Export Control Law, to rule out the interference of contemporaneous shocks; Column (2) excludes the G7 countries (namely, the United States, Japan, Germany, France, Italy, the United Kingdom, and Canada) to test whether the baseline finding is driven solely by these large, technologically advanced developed economies; and Column (4) retains only countries that appear continuously throughout the sample period to form a balanced panel, to rule out the influence of sample composition changes. In terms of variable treatment, Columns (3) and (6) winsorize the core explanatory variable and the dependent variable at the 1 percent level, respectively, to rule out the interference of extreme observations. In terms of data reporting, Column (5) reconstructs the trade network from importer-reported data for a mirror sensitivity check, to rule out the influence of reporting direction. Across all six specifications the core coefficient is negative in direction, with Column (4) significant at the 1 percent level, Column (5) significant at the 5 percent level, and the remaining columns significant at the 10 percent level, so the robustness tests support the baseline results. In addition, this article adjusts the minimum trade threshold from 1,000 US dollars to 500 and 2,000 US dollars for sensitivity checks; the core coefficient remains negative and significant at the 10 percent level. Since these results involve only two specifications, they are not reported separately in Table 4. In addition, to alleviate concerns about sample-selection bias, we compare the characteristics of the observations included in and excluded from the baseline regression and find no systematic differences (see Appendix A); we also re-estimate the model after dropping each G7 member one at a time, and the core coefficient remains negative and significant (see Appendix B).

## 5.5 Moderating effects

Table 5 reports the results of the moderating-effect tests for resource endowment and industrial structure. Grouping by resource endowment shows that in the high-resource-endowment group the coefficient of upstream export dependence asymmetry (CD) is −0.073 and significant at the 5 percent level, while it is insignificant in the low-resource-endowment group, thus supporting H2. This means that partner countries positioned upstream in the rare earth industrial chain and mainly engaged in ore extraction and export are more vulnerable as dependence deepens,

TABLE 4 Robustness tests.

| Variable | (1) Excluding 2020 | (2) Excluding G7 | (3) Winsorized explanatory variable (1%) | (4) Winsorized dependent variable (1%) | (5) Balanced panel | (6) Mirror data (importer-reported) |
|---|---|---|---|---|---|---|
| CD | −0.057* (0.030) | −0.054* (0.030) | −0.053* (0.028) | −0.054* (0.029) | −0.077*** (0.025) | −0.055** (0.022) |
| Control variables | Yes | Yes | Yes | Yes | Yes | Yes |
| Country fixed effects | Yes | Yes | Yes | Yes | Yes | Yes |
| Year fixed effects | Yes | Yes | Yes | Yes | Yes | Yes |
| Observations | 534 | 526 | 587 | 580 | 340 | 593 |
| $R^2$ | 0.069 | 0.061 | 0.059 | 0.059 | 0.221 | 0.117 |

***, ** and * denote significance at the 1%, 5% and 10% levels, respectively.

TABLE 5 Moderating effects of resource endowment and industrial structure.

| Variable | (1) High resource endowment | (2) Low resource endowment | (3) Strong manufacturing base | (4) Weak manufacturing base |
|---|---|---|---|---|
| CD | −0.073** (0.036) | −0.016 (0.064) | 0.075** (0.027) | −0.088*** (0.030) |
| Control variables | Yes | Yes | Yes | Yes |
| Country fixed effects | Yes | Yes | Yes | Yes |
| Year fixed effects | Yes | Yes | Yes | Yes |
| Observations | 176 | 228 | 296 | 283 |
| $R^2$ | 0.171 | 0.102 | 0.132 | 0.143 |

***, ** and * denote significance at the 1%, 5% and 10% levels, respectively.

TABLE 6 Heterogeneity tests across other dimensions.

| Variable | (1) High income | (2) Low income | (3) High trade openness | (4) Low trade openness |
|---|---|---|---|---|
| CD | 0.049 (0.028) | −0.086** (0.034) | −0.087** (0.042) | −0.044 (0.042) |
| Control variables | Yes | Yes | Yes | Yes |
| Country fixed effects | Yes | Yes | Yes | Yes |
| Year fixed effects | Yes | Yes | Yes | Yes |
| Observations | 313 | 273 | 281 | 298 |
| $R^2$ | 0.130 | 0.131 | 0.143 | 0.102 |

***, ** and * denote significance at the 1%, 5% and 10% levels, respectively.

because they concentrate their rare earth ores heavily on exports to China and lack alternative sales channels in the face of China as a monopsonistic buyer. Grouping by manufacturing base shows that in the weak-manufacturing-base group the coefficient of CD is −0.088 and significant at the 1 percent level, while it is insignificant in the strong-manufacturing-base group, thus supporting H3. This result is consistent with the exit-cost logic of Baldwin (1980): partner countries with weak manufacturing bases lack the capacity for processing, transformation, and substitute production, and find it difficult to absorb China's upstream advantage through industrial structure adjustment, so the negative association is stronger.

## 5.6 Heterogeneity analysis

To further examine other boundary conditions of the asymmetric dependence effect, this article also conducts grouping tests by income level and trade openness, with the results reported in Table 6. Grouping by income level shows that in the low-income group the coefficient of CD is −0.086 and significant at the 5 percent level, while it is insignificant in the high-income group, indicating that partner countries with lower levels of economic development and relatively simple economic structures lack sufficient adjustment and buffering capacity in the face of asymmetric dependence and are therefore more vulnerable. Grouping by trade openness shows that

in the high-openness group the coefficient of CD is −0.087 and significant at the 5 percent level, while it is insignificant in the low-openness group; this may be because the trade networks of highly open partner countries are more sensitive to external linkages, so that once their dependence on China deepens, the contracting effect of their trade linkages concentrating toward China is more pronounced. The above results further confirm that the vulnerability effect of asymmetric dependence is mainly concentrated among partner countries with relatively weak economic structures and limited adjustment capacity.

# 6 Further analysis

Building on the preceding analysis, this article further conducts tests from the perspective of endogeneity, to rule out the interference of reverse causality or common determination on the baseline findings. Specifically, on the one hand, this article re-estimates the baseline model using the system generalized method of moments (SYS-GMM), controlling for dynamic dependence and potential endogeneity; on the other hand, it uses a symmetric simultaneous equations model to examine the reverse association.

## 6.1 System GMM estimation

To alleviate potential endogeneity problems, this article re-estimates the baseline model using the system generalized method of moments (SYS-GMM). System GMM uses the differenced and level values of lagged dependent variables and endogenous explanatory variables as instruments, and can alleviate the estimation bias caused by reverse causality and omitted variables while controlling for unobservable individual effects and dynamic dependence. The results show that the coefficient of upstream export dependence asymmetry (CD) is −0.069 and significantly negative at the 5 percent level, consistent in direction and comparable in magnitude with the baseline regression, indicating that the core conclusion of this article remains robust after accounting for dynamic dependence and potential endogeneity. In addition, the results of estimating CD lagged by one and two periods show that the lagged terms do not pass the significance test, indicating that the association between asymmetric dependence and resilience is mainly a contemporaneous effect; the two-stage estimation using resource rents as an instrument for CD is not adopted because the instrument does not satisfy the exclusion restriction.

## 6.2 Simultaneous equations model

The core argument of this article is that China's upstream structural advantage relative to its trading partners is negatively associated with partner country trade network resilience. At the same time, a potential concern is that, since both upstream export dependence asymmetry and trade network resilience are constructed from trade data, the two may exhibit reverse association or common determination. To examine this possibility, this article further adopts a symmetric simultaneous equations model for supplementary testing.

This article constructs a symmetric simultaneous equations model in which partner country trade network resilience and upstream export dependence asymmetry each serve as the dependent variable in their respective equations, with consistent control variables, country fixed effects and year fixed effects included in both equations. The results are reported in Table 7. The estimation results show that in the equation with TNR as the dependent variable, the CD coefficient is significantly negative at the 10 percent level; whereas in the equation with CD as the dependent variable, the TNR coefficient is negative but does not pass the significance test. It should be emphasized that this symmetric regression does not introduce exclusion instruments and does not constitute causal identification; the results of the two equations only reflect the bidirectional association within the sample.

Therefore, this article does not interpret the results of the above symmetric regression directionally, but treats it only as a supplementary association test: the within-sample reverse association is not significant, but this result can neither rule out reverse causality nor rule out common determination, and the core conclusions of this article remain uniformly expressed in terms of association.

Taken together, the results of the system GMM estimation and the symmetric simultaneous equations model yield two supplementary insights beyond the baseline findings. First, after controlling for dynamic dependence and potential endogeneity, the negative association between upstream export dependence asymmetry and partner country resilience remains significant at the 5 percent level. Second, the symmetric simultaneous equations estimation finds no significant

TABLE 7 Endogeneity tests.

| Variable | (1) System GMM | (2) CD → TNR | (3) TNR → CD |
|---|---|---|---|
| CD | −0.069** (0.028) | −0.053* (0.028) | |
| TNR | | | −0.743 (0.455) |
| Control variables | Yes | Yes | Yes |
| Country fixed effects | Yes | Yes | Yes |
| Year fixed effects | Yes | Yes | Yes |
| Observations | 547 | 587 | 598 |
| $R^2$ | | 0.059 | 0.094 |

***, ** and * denote significance at the 1%, 5% and 10% levels, respectively.

reverse association, but owing to the lack of an identification strategy, this result cannot rule out the possibility of reverse causality or common determination.

# 7 Conclusions and policy implications

## 7.1 Research conclusions

Drawing on the 2013–2024 UN Comtrade data on rare earth full-industry-chain trade, this article constructs the global rare earth trade network, measures the trade network resilience of China's rare earth trading partners at the partner country level, and, taking the upstream export dependence asymmetry of China relative to specific trading partners as the core explanatory variable, systematically examines the impact of asymmetric dependence on partner country trade network resilience and its boundary conditions. Integrating the baseline regression, robustness tests, heterogeneity analysis, and further analysis, this article draws the following three conclusions.

First, in the rare earth full-industrial-chain network, there is a robust negative association between upstream export dependence asymmetry and partner country structural trade network resilience. After controlling for country fixed effects, year fixed effects, and a set of country characteristics, the coefficient of upstream export dependence asymmetry (CD) is significantly negative, and is significant at the 1 percent level in the balanced panel of countries observed in all twelve consecutive years. From a dimensional perspective, this negative association is driven mainly by the two dimensions of structural stability and diversification: the coefficient of CD on structural stability is significant at the 5 percent level and the coefficient on diversification is significant at the 10 percent level, while the coefficient on connectivity is insignificant. That is, the deeper a partner country's dependence on ore exports to China, the more unbalanced its trade flow distribution and the more concentrated its export markets, and the lower its structural network resilience. In plain terms, when a partner country concentrates its rare earth ores heavily on exports to China and is locked in by China as a monopsonistic buyer, its export channels and trade structure narrow and become unbalanced, and its shock-absorbing capacity declines.

Second, the negative association between asymmetric dependence and partner country trade network resilience is clearly conditional. Grouping estimation by resource endowment shows that among partner countries with stronger resource endowments, the coefficient of upstream export dependence asymmetry is significantly negative at the 5 percent level, while among partner countries with weaker resource endowments the coefficient is insignificant. This is because partner countries with stronger resource endowments are mostly positioned upstream in the rare earth industrial chain and mainly engaged in ore extraction and export, their rare earth exports are highly concentrated in the Chinese market, and their adjustment rigidity is greater, so the negative association is more pronounced.

Third, as a supplementary test, the symmetric simultaneous equations estimation finds no significant reverse association; however, it should be emphasized that, owing to the lack of exclusion instruments, all estimates in this article are association results and cannot be used to make causal or directional inferences.

From an international political economy perspective, the findings reveal the dual nature of asymmetric dependence: on the one hand, partner countries may gain certain opportunities for trade-structure diversification through their dependence on China; on the other hand, such dependence exposes them to rising strategic vulnerability. This coexistence of diversification and vulnerability is precisely the concrete manifestation of power-dependence theory and weaponized interdependence theory in the strategic mineral domain, and constitutes the main contribution of this article to the international political economy literature.

This article also has some limitations. First, the partner country trade network resilience measured in this article is structural resilience based on annual trade structures, rather than the actual recovery resilience following specific shocks, the latter of which awaits examination with higher-frequency data in the future. Second, upstream export dependence asymmetry requires the relevant bilateral trade flows to be positive, and both it and trade network resilience are constructed from rare earth trade data, so the two share some common components; although this article has mitigated this through mirror checks and dimension-wise checks, mechanical correlation is still difficult to exclude entirely. At the same time, the raw data do not contain reporting-status indicators, so this article cannot fully distinguish missing values from true zero trade. Finally, integrated circuits and lasers, incorporated into the trade network as downstream applications, are not pure rare earth products, which may affect the precision of the network measurement to some extent. These limitations also point to directions for future research; with finer-grained data and a richer set of partner countries, the robustness and applicability of the conclusions can be further examined.

## 7.2 Policy implications

Based on the above conclusions, the practical implications of this article concern both the dependence management and alliance coordination of partner countries and the industrial chain competitiveness of China itself, and are mainly reflected in the following four respects:

First, partner countries should proactively manage their dependence on China and guard against the risk of declining structural resilience. The results indicate that upstream export dependence is associated with the imbalance of a partner country's trade flow distribution and the concentration of its export markets. Therefore, while making use of China's rare earth processing system, partner countries should diversify their supply chains, cultivate alternative sources, and strengthen regional cooperation, so as to avoid excessive dependence on a single core node and safeguard their supply security across the rare earth full industrial chain.

Second, for partner countries with weak industrial structures and limited substitution capacity, their dependence on China is more readily converted into a narrowing of trade linkages. Therefore, while making use of China's rare earth processing system, such partner countries should accelerate the cultivation of their own processing and transformation capacity and alternative sources, so as to reduce their dependence on a single core node.

Third, the tension of 'coexistence of structural diversification opportunities and strategic vulnerability' revealed in this article means that partner countries face a profound political-economic trade-off in their dependence on China: dependence on China may bring certain trade-structure diversification, but it is also accompanied by rising strategic vulnerability. This trade-off should be an important consideration when partner countries formulate critical mineral policies and advance supply chain restructuring.

Fourth, the sustainability of China's core position in rare earths depends, in the final analysis, on midstream and downstream organizational capacity rather than on resource endowments alone. Consolidating the comprehensive competitiveness of smelting and separation, functional materials, permanent magnet devices, and the associated standard systems remains the key to maintaining China's core position in the rare earth full industrial chain.

## Data availability statement

The data used in this study are publicly available from the UN Comtrade database (https://comtradeplus.un.org/) and the World Bank WDI database (https://databank.worldbank.org/source/world-development-indicators). The processed data supporting the conclusions of this article will be made available by the authors upon reasonable request.

## Author contributions

XM: Formal analysis, Writing – original draft, Data curation, Visualization. CL: Writing – review & editing, Conceptualization, Funding acquisition, Supervision, Methodology. LF: Investigation, Writing – review & editing.

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## Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpos.2026.1952240/full#supplementary-material

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