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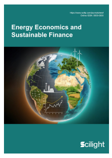

Article

Barometer of Great-Power Rivalry: Bidirectional Dynamic Causality between US–China Tensions and Rare Earth Prices

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Abstract: This study examines whether a dynamic causal relationship exists between U.S.–China tensions (RUCT) and rare earth prices (RREPI). Employing a bootstrap rolling-window causality test on monthly data from June 2014 to January 2026, we find a significant time-varying relationship. U.S.–China tensions significantly increased rare earth prices during three periods: August–October 2022, and December 2025–January 2026. Conversely, rare earth prices exerted a weak intensifying effect on tensions during July–September 2023, July–September 2024, and September–November 2025. The analysis indicates that technological sanctions, export controls, and geopolitical conflicts raise prices, while escalating trade frictions suppress them by weakening global demand. These findings suggest rare earths have transitioned from commodities into "geopolitical risk assets", carrying a strategic rivalry premium. A bidirectional, asymmetric feedback mechanism exists between their prices and bilateral relations. The study provides dynamic evidence on strategic resources in great-power competition and offers insights for building resource security and early-warning systems.

Keywords: U.S.–China tensions; rare earth prices; geopolitical risk; bootstrap rolling-window causality test

JEL Classification: F51; F52; Q37

1. Introduction

At present, U.S.–China strategic competition has become an increasingly central structural force shaping the global political economy [1,2]. As indispensable strategic minerals for high-tech industries, the green-energy transition, and defense applications [3], rare earths display market dynamics and price volatility that are not fully captured by conventional supply–demand frameworks. China's dominance across the rare-earth supply chain—from resource endowments to advanced processing—renders this commodity intrinsically geopolitical [4]. When bilateral relations deteriorate, market participants and policymakers often expect rare earths to be used as a bargaining instrument, prompting sharp price movements and a reassessment of supply-chain risks. Against this backdrop, examining the dynamic causal relationship between U.S.–China tensions and rare earth prices is important for assessing global strategic-resource security, informing market-risk monitoring, and evaluating the economic consequences of great-power rivalry.

Based on available data, China has a prominent position in the global rare earth supply chain since it now produces around 70% of the world's rare earths and retains about 48.9% of its reserves. Against this backdrop, fluctuations in rare earth prices have increasingly been shaped by geopolitical tensions, particularly in the context of U.S.–China relations. In recent years, major geopolitical events have been closely associated with pronounced movements in rare earth prices. For example, following the launch of the United States' Section 301 investigation against China in August 2017, the Rare Earth Price Index (REPI) rose sharply. Similarly, the start of the Russia–

Ukraine war in February 2022 also resulted in increased pricing of essential resources, including rare earth elements, to rise. By 2025, U.S.–China relations remained persistently strained amid ongoing tariff disputes, technology-related sanctions, and heightened geopolitical frictions. Notable developments included the mutual imposition of tariffs in May 2025, U.S. arms sales to Taiwan later that year, and China's subsequent tightening of export controls on rare earths to the United States. These events coincided with a marked increase in the REPI during the 2025–2026 period. Overall, these price dynamics suggest that rare earths have increasingly evolved from conventional industrial commodities into "geopolitical risk assets", whose prices exhibit heightened sensitivity to shifts in U.S.–China strategic competition. This transformation reflects the extent to which concerns over supply chain security and expectations of prolonged strategic rivalry are rapidly capitalized into market prices. In this way, rare earths should be viewed as vital tools that price and communicate geopolitical risk and the strategic interactions between superpowers, rather than just as economic inputs.

Previous research concentrated on examining the effects of strategic resources and geopolitical risk; however, research remains clearly limited with respect to the specific context of U.S.–China tensions and the particular commodity of rare earths. First, many studies either focus on the influence of broad geopolitical risk on commodity markets without isolating the distinctive driver of the bilateral U.S.–China relationship, or examine only single episodes such as the trade war, making it difficult to reveal the long-run, dynamic evolution. Second, methodologically, widely used static models or full-sample Granger causality tests implicitly assume constant parameters, and thus cannot effectively capture structural breaks induced by major policy turning points in the bilateral relationship—such as technology sanctions and export controls—which may obscure heterogeneity across historical phases. Finally, much of the existing analysis presumes a unidirectional logic in which conflict drives prices, overlooking the possibility that surging rare earth prices may, by raising downstream industrial costs and affecting defense budgets and supply-chain security, in turn shape U.S. domestic political debates and the intensity of China-related policy. This potential bidirectional, time-varying, and asymmetric interaction mechanism has yet to be subjected to rigorous empirical testing.

This study addresses these gaps by using a bootstrap rolling-window causality test to analyze the dynamic causal link between rare earth prices and tensions between the United States and China. The marginal contributions are threefold. First, rather than relying on broad geopolitical-risk indicators, the "U.S.–China Tension Index" (UCT), constructed from news-text big data, is adopted as the core explanatory variable, providing a continuous and quantitative measure of bilateral tension. Second, the bootstrap rolling-window causality approach is introduced without presupposing parameter stability; rolling time windows are used to dynamically identify and characterize time-varying causal linkages, offering a more robust analytical framework for international-relations and market data characterized by structural breaks. Third, beyond establishing a significant effect of UCT on rare earth prices, the analysis further documents a reverse effect of rare earth prices on UCT in specific periods. These findings provide micro-level evidence and mechanism-based interpretation that better reflect real-world dynamics, thereby enriching understanding of the role of strategic resources in complex great-power rivalry.

2. Literature Review

Around the central theme of this study, the existing literature can be broadly organized into three main strands.

First, a substantial body of research analyzes the impact of geopolitical risk (GPR) on commodity prices. The prevailing view in this literature is that geopolitical risk constitutes a significant exogenous shock to commodity markets, primarily influencing price volatility through disruptions to supply expectations, adjustments in risk premia, and intensified financial speculation [5]. Numerous empirical studies in the energy market sector have verified a strong relationship between geopolitical concerns and the volatility of crude oil prices. Liu et al. [6] and Qian et al. [7] indicate that severe geopolitical risks can significantly elevate risk premiums in the crude oil market and have predictive significance in asset allocation. Khan et al. [8] argue that geopolitical risks have become a key determinant of oil prices by affecting global energy transport routes and inventory expectations. Monge et al. [9] further extend the analysis to the shipping market, showing that geopolitical tensions not only affect oil prices directly but also amplify energy price volatility through freight rate transmission channels. As research perspectives have broadened, a growing thread of the literature has begun to explore the effects of geopolitical conflicts on agricultural commodities and base metals, thereby extending the scope of geopolitical risk beyond energy markets. Hudecová and Rajčániová [10] noted in their study of the Russia-Ukraine conflict that military hostilities have heightened instability in global food and commodity markets. Ren et al. [11] reveal from a quantile perspective that geopolitical risks exert a markedly nonlinear influence on crude oil prices: primarily manifesting as negative shocks in low quantile intervals, while potentially transforming into positive impacts in high quantile intervals. At the broader commodity level, Mo et al. [12] found that geopolitical risks exert a negative average impact on commodity prices. However, during bullish market conditions, geopolitical shocks are often interpreted by markets as signals of potential supply constraints, thereby driving prices higher. From the standpoint of financialization, Zhou and Liang [13] contend that geopolitical threats have the potential to produce speculative bubbles by causing gold prices to diverge from their intrinsic value.

Second, a growing body of research examines how U.S.-China ties affect particular financial and economic factors. Wang [1] noted earlier that a complex interplay exists between bilateral trade and political conflicts between China and the United States: at different historical junctures, trade may either mitigate political tensions or, under specific circumstances, amplify the risk of conflict. Subsequently, Polachek and Seiglie [14,15], building upon the "trade promotes peace" theory, argued that economic interdependence moderates interstate conflict to some extent but is not universally effective. As strategic competition between China and the U.S. deepens, related research has increasingly focused on trade frictions, technology restrictions, and supply chain restructuring. Song et al. [16] discovered that U.S.–China political ties have both beneficial and detrimental impacts on bilateral commerce, with the adverse effect on Chinese imports being far more pronounced than that on exports. Handley and Limão [17] and Crowley et al. [18] point out that trade policy uncertainty itself can have long-term negative effects on corporate investment and the layout of global value chains. At the financial level, some studies indicate that deteriorating U.S.–China relations can influence capital market volatility through uncertainty channels [19,20]. In the realm of strategic resources, Wang et al. [21] employed a TVP-VAR model to reveal that U.S.–China relations and uncertainties in climate policy are substantial factors influencing the volatility of rare earth prices, with the supply-demand structure of rare earths playing a crucial mediating role.

Third, a smaller but rapidly expanding body of literature investigates the relationship between geopolitics and the rare earth market. Unlike conventional commodities, rare earth elements are widely classified as "critical minerals" and "strategic resources", reflecting their non-substitutability and essential role in high-end manufacturing, defense-related industries, and emerging energy technologies. Chapman [22] documents that, despite possessing limited domestic rare earth reserves, the United States remains highly dependent on China for mining, separation, and processing activities, implying that potential supply chain disruptions could generate systemic repercussions for both economic stability and national security. From an empirical perspective, Fan et al. [23] show that rare earth metal import prices are positively associated with geopolitical risk, whereas total import values exhibit a negative correlation, suggesting that periods of heightened geopolitical tension are characterized by rising prices alongside contracting trade volumes. Complementing this evidence, Li et al. [24] employ a wavelet decomposition framework and find that rare earth prices respond significantly and positively to geopolitical risk shocks, underscoring their strategic importance and potential hedging properties during episodes of elevated uncertainty. Furthermore, some studies indicate that rare earth price fluctuations can influence national policy expectations and international negotiating positions [25], suggesting that rare earth prices themselves may serve as a "signaling variable" in great power rivalry.

In summary, a significant body of research demonstrates that geopolitical risk is a primary factor influencing commodity price volatility, particularly in energy and metal markets, and documents the multifaceted effects of U.S.–China relations on trade, finance, and related economic outcomes. More recently, a growing strand of the literature has emphasized the distinctive geopolitical characteristics of the rare earth market, demonstrating that rare earth prices and supply-chain security are highly sensitive to political developments. However, the majority of current research relies on general geopolitical risk indices, which makes it challenging to pinpoint the precise function of U.S.–China bilateral tensions. Moreover, the prevailing use of static or full-sample estimation frameworks limits the ability to capture structural breaks induced by major policy events as well as the time-varying characteristics of causal interactions in the rare earth market.

3. Theory and Model

3.1. Theoretical Analysis

Against the backdrop of intensifying strategic competition between China and the U.S. and ongoing reconfigurations of global industrial value chains, rare earths—classified as critical minerals with high technological dependence and defense sensitivity—have experienced price formation processes that increasingly extend beyond traditional supply–demand fundamentals. Drawing on insights from geopolitical economics, international relations, and market microstructure theory, this study seeks to clarify the dynamic causal link between the United States and China tensions and rare earth price dynamics.

First, based on the theory of "supply security anxiety" in geopolitical economics, the high concentration of the rare earth supply chain and China's dominance across the entire chain mean that any signals of bilateral tension may be interpreted by the market as a potential risk of supply disruption [26]. Under conditions of incomplete information and the mechanism of self-fulfilling expectations, downstream manufacturers and speculators may adopt preventive stockpiling, seek alternative suppliers, or adjust inventory strategies based on their anticipation of policy risks such as export controls and trade sanctions. This collective behavior distorts actual supply and demand in the short term, leading to price overshoots. This phenomenon is particularly pronounced during critical windows involving "high-deterrence signals" such as technological blockades and military sanctions. Therefore, we anticipate that escalating tensions between China and the U.S.—particularly incidents involving technology sanctions or export controls—will positively impact rare earth prices by triggering expectations of supply contraction.

Second, from the perspective of market risk pricing, rare earths have exhibited characteristics of a "political risk asset". Asset pricing theory indicates that when an asset's future cash flows are significantly affected by policy uncertainty, investors demand an additional risk premium as compensation [27–29]. The policy uncertainty stemming from U.S.–China tensions encompass not only direct trade and export restrictions but also extended risks such as investment reviews, diverging technical standards, and even long-arm jurisdiction. This uncertainty heightens the anticipated risk of holding or trading rare earths, thereby increasing the risk premium component in their prices [30]. In increasingly financialized commodity markets, this risk premium may be further amplified and anticipated through financial channels such as futures markets and ETFs.

Furthermore, insights from international trade theory and game theory suggest that interstate interactions over strategic resources can be characterized as repeated and signaling games [31]. In this context, China's rare earth export policies may serve not only economic purposes but also strategic signaling functions, conveying policy resolve, exerting deterrence, or facilitating bargaining in bilateral negotiations [32]. Similarly, the United States' policy efforts to promote self-reliance in rare earth supply chains can be interpreted as a strategic response to perceived dependence-related vulnerabilities. Within such a strategic interaction framework, rare earth prices are not merely outcomes of market supply and demand, but may also function as informational signals through which both sides infer each other's policy intentions and strategic positioning. Consequently, abnormal price fluctuations may themselves feed back into U.S. policy assessments and domestic political discourse. For example, sharp price increases could amplify concerns over supply-chain fragility, thereby strengthening political support for the adoption or persistence of more confrontational policy stances toward China.

H1: *When U.S.–China tensions are driven by technology sanctions, export controls, or geopolitical events involving core strategic interests, escalating tensions significantly increase rare earth prices by strengthening expectations of supply constraints and higher risk premia.*

H2: *When U.S.–China tensions primarily take the form of escalating comprehensive trade frictions, and market attention focuses on their potential suppression of global aggregate demand, heightened tensions may exert a dampening effect on rare earth prices through demand-expectation channels.*

H3: *When rare earth prices rise sharply, major consuming nations' perceptions of supply-chain fragility and associated strategic fears are heightened, which has a positive feedback effect on bilateral tensions between the United States and China.*

3.2. Bootstrap Rolling-Window Causality Test

This research used the RB-adjusted LR statistic to analyze Granger causality links among the variables. The VAR(p) model is defined as follows:

$$Y_t = \alpha_0 + \sum_{k=1}^{p} \alpha_k Y_{t-k} + u_t\,,\; t = 1,2,...,T, \tag{1}$$

The lag order p is selected using the SIC, and the optimal lag length is p = 2. Then, splitting Y in each bivariate VAR(p) into $RUCT_t$ and $RREPI_t$, and Equation (1) can be written as:

$$\begin{bmatrix} RUCT_t \\ RREPI_t \end{bmatrix} = \begin{bmatrix} \alpha_{10} \\ \alpha_{20} \end{bmatrix} + \begin{bmatrix} \alpha_{11}(L) & \alpha_{12}(L) \\ \alpha_{21}(L) & \alpha_{22}(L) \end{bmatrix} \begin{bmatrix} RUCT_t \\ RREPI_t \end{bmatrix} + \begin{bmatrix} \upsilon_{1t} \\ \upsilon_{2t} \end{bmatrix} \tag{2}$$

Here, $\upsilon_t = (\upsilon_{1t}, \upsilon_{2t})'$ is a zero-mean white noise process, and $\alpha_{ij}(L) = \sum_{k=1}^{p} \alpha_{ij,k} L^k$, i,j = 1,2, with $L^k Y_t = Y_{t-k}$.

Equation (2) evaluates the absence of Granger causality from RUCT to RREPI by imposing joint limitations: $H_0{:}\alpha_{12,k} = 0$ for k = 1, 2, ⋯, p. Rejection of this restriction supports Granger causality running from RUCT to RREPI. The reverse direction is assessed in the same manner by testing $H_0{:}\alpha_{21,k} = 0$ for k = 1, 2, ⋯, p.

3.3. Bootstrap Sub-Sample Rolling-Window Causality and Parameter Stability Testing

Conventional full-sample bootstrap Granger causality tests rely on the assumption that VAR parameters remain structurally stable over time. In practice, however, this assumption is often violated, particularly in the presence of major policy shifts or geopolitical shocks. When model parameters vary across the sample period, full-sample causality tests may yield biased or misleading inferences. The Sup-F, Ave-F, and Exp-F tests put out by Andrews (1993) are used to formally analyze parameter stability to overcome this problem. The Sup-F test is intended to identify abrupt structural changes, whereas the Ave-F and Exp-F tests are employed to assess if parameters progress incrementally across a temporal trajectory. In addition, to test for random walk dynamics in the parameters, the Lc statistics created by Nyblom [33] and Hansen [34] are applied. These tests make it possible to assess whether time-varying interactions exist between RUCT and RREPI (used here as illustrative examples). When such interactions are detected, the Granger causality relationship between the two variables is further investigated using a bootstrap rolling-window sub-sample approach.

The above-mentioned methodology, originally proposed by Balcilar et al. [35], partitions the full time-series dataset into a sequence of compact sub-samples determined by a rolling window. From the start of the sample period to its conclusion, the sub-samples are methodically rolled forward. This method's primary benefit is that it makes it possible to identify time-varying associations between variables, exposing dynamic correlations that full-sample estimations can miss [36]. The procedure is implemented as follows. Let l be the rolling window's width and T be the time series' length. Each sub-sample has an endpoint defined as l, l + 1, ..., T, resulting in a total of T – l + 1 sub-samples. For each sub-sample, an RB modified LR test is performed to examine the existence of Granger causality. Subsequently, the sequence of p-values together with the corresponding LR test statistics from all sub-samples is organized over time to construct the bootstrap rolling-window causality test outcomes [37]. The statistic $N_b^{-1}\sum_{k=1}^{p}\hat{\alpha}_{12,k}^{*}$ represents the mean of a substantial quantity of bootstrap estimates and captures the effect of RREPI on RUCT (and vice versa), where N_b represents the quantity of bootstrap replications and $\hat{\alpha}_{12,k}^{*}$ corresponds to the parameter defined in Equation (1). A 90% confidence interval is established, specified by the 5th and 95th percentiles of the bootstrap distribution as the lower and upper bounds, respectively [35]. The choice of the rolling-window width involves a nontrivial trade-off. A window that is too narrow may undermine the reliability of the test outcomes, while a wider window, although enhancing estimation precision, reduces the number of rolling iterations. Pesaran and Timmermann [38] recommended that when parameter stability cannot be guaranteed, the rolling-window width should not be less than 20 observations.

4. Sources of Data and Variable Description

4.1. Data Sources and Sample Selection

To investigate bidirectional time-varying causality between U.S.–China tensions and rare earth prices, bilateral tensions are measured by the UCT Index, while rare earth prices are proxied by the Rare Earth Price Index compiled by the China Rare Earth Industry Association. The analysis utilizes monthly data spanning from June 2014 to January 2026. A monthly data frequency is adopted to capture medium- to long-term dynamics in bilateral relations and resource price movements, while mitigating the noise typically associated with higher-frequency data. This choice facilitates a more reliable identification of the dynamic transmission mechanisms between the variables. To ensure the validity of subsequent econometric analyses, all raw time series were subjected to rigorous data cleaning and stationarity preprocessing. Non-stationary variables were transformed using first-order log-differencing, yielding two stationary series: the rate of change in China–U.S. tensions (RUCT) and the rate of change in rare earth prices (RREPI). These transformed series constitute the basis for the rolling-window causality tests.

4.2. U.S.–China Tension Index

Rogers et al. [39], extending the text-based index-construction approach of Baker et al. [20] for the EPU Index, develop the UCT using coverage from major U.S. newspapers. The index is predicated on the proportion of articles that include language related to disputed issues and heightened tensions between the United States and China, with relevant textual features and topic structure extracted via a suite of techniques—such as K-means clustering, guided LDA, and Newsmap analysis, among others. The resulting UCT provides a continuous, quantitative gauge of bilateral tensions and is employed in this study as the proxy for U.S.–China tensions. The data are obtained from the Economic Policy Uncertainty (http://www.policyuncertainty.com/US_China_Tension.html (accessed on 17 May 2026) database. This index provides an objective and continuous measure of real-time perceptions and anticipated changes in market- and policy-level tensions between the two countries by systematically quantifying the intensity of bilateral dispute coverage in mainstream media. In doing so, it overcomes key limitations of traditional event-based and survey-based measures, particularly with respect to continuity, timeliness, and objectivity.

4.3. Rare Earth Price Index

Based on the U.S. Geological Survey's Mineral Commodity Summaries 2025, China holds 48.9% of worldwide rare earth stocks and constitutes roughly 70% of global rare earth production. Accordingly, this study uses the Rare Earth Price Index (https://datatrack.trendforce.com/Chart/content/3228/rare-earth-price-index (accessed on 18 May 2026)) (REPI) assembled by the China Rare Earth Industry Association as a proxy for rare earth price levels. The data are obtained from the Choice (https://www.choice-china.com/ (accessed on 18 May 2026)) database. The index provides a comprehensive measure of market transaction prices for major rare earth oxides and metals, such as lanthanum, cerium, praseodymium, and neodymium. Its authoritative compilation, reliance on direct market data, and timely, continuous updates have made it a key benchmark for both academic research and industry practice in monitoring rare earth market trends in China and worldwide.

Comprehensive descriptions of all variables are shown in Table 1.

Table 1. Definitions of variables.

Variable	Symbol	Description/Transformation	Frequency
U.S.–China Tension Index	UCT	Level (index)	Monthly
Rare Earth Price Index	REPI	Level (index)	Monthly
Change rate of U.S.–China Tension Index	RUCT	First difference of ln(UCT)	Monthly
Change rate of Rare Earth Price Index	RREPI	First difference of ln(REPI)	Monthly

4.4. Descriptive Statistics

Table 2 presents the descriptive statistics for all variables. The skewness coefficients of UCT and REPI are both positive and sizeable, with values of 1.572 and 1.544, respectively, indicating pronounced right-skewed distributions. This suggests that extreme high observations occur more frequently than would be expected under normality. Consistent with this pattern, the kurtosis coefficients of UCT (5.209) and REPI (4.960) substantially exceed the benchmark value of 3, implying significant peakedness and fat-tailed behavior. Such distributional features are typical of economic and financial time series. The ADF, PP, and KPSS tests are utilized collectively to evaluate the stationarity characteristics of the series. The null hypothesis of a unit root for REPI is not rejected by the ADF and PP tests at standard significance levels, but the null of stationarity is rejected by the KPSS statistics for both UCT and REPI, which are statistically significant at the 1% level. Taken together, these results consistently indicate that UCT and REPI are non-stationary over the sample period and therefore unsuitable for direct use in subsequent econometric modeling.

Accordingly, first-order logarithmic differences are applied to UCT and REPI, yielding RUCT and RREPI, which represent the monthly changes in U.S.–China tensions and rare earth price returns, respectively. The differenced series exhibit substantially reduced skewness, with coefficients of 0.458 for RUCT and 0.017 for RREPI, though both remain mildly right-skewed. The kurtosis values of RUCT (5.577) and RREPI (3.741) continue to exceed the normal benchmark, indicating persistent fat-tailed characteristics commonly observed in financial and economic volatility measures. As shown in Table 2, both the ADF and PP tests strongly reject the unit root null for RUCT and RREPI at the 1% significance level, confirming that the differenced series are stationary. These properties satisfy the statistical prerequisites for the subsequent rolling-window causality analysis.

Table 2. Descriptive statistics and unit-root tests.

Statistic	UCT	REPI	RUCT	RREPI
Obs.	141	141	141	141
Mean	157.274	178.389	0.009	0.002
Median	141.830	151.420	0.004	0.000
Max.	349.946	415.570	0.787	0.195
Min.	82.196	109.300	−0.529	−0.192
Std.dev.	52.720	66.651	0.178	0.068
Skewness	1.572	1.544	0.458	0.017
Kurtosis	5.209	4.960	5.577	3.741
ADF	−3.446 **	−1.741	−15.627 ***	−8.504 ***
PP	−3.131 **	−1.583	−20.155 ***	−7.825 ***
KPSS	35.297 ***	31.669 ***	0.603	0.407

Note: **, *** indicate statistical significance at the 1% and 0.1% levels, respectively.

4.5. Time Trends of Variables

Figure 1 plots the time-series dynamics of the variables. As shown in Figure 1, UCT and REPI exhibit broadly similar overall trends, and both series display pronounced short-term fluctuations. The co-movement between the two series becomes particularly pronounced during major geopolitical and macroeconomic events. For instance, the initiation of the United States' Section 301 investigation against China in August 2017 marked the onset of heightened trade frictions, after which the Rare Earth Price Index (REPI) exhibited a sustained upward trajectory, reaching its peak within the 2014–2021 sample period in 2020. Similarly, the outbreak of the Russia–Ukraine conflict in February 2022 intensified global security concerns surrounding strategic resources, contributing to another sharp increase in REPI. In early 2025, market volatility increased sharply as geopolitical tensions resurfaced, driven by Trump's return to the U.S. presidency, reciprocal tariff escalations in May, and China's targeted restrictions on rare earth exports. These shocks coincided with a sustained rise in REPI through early 2026.

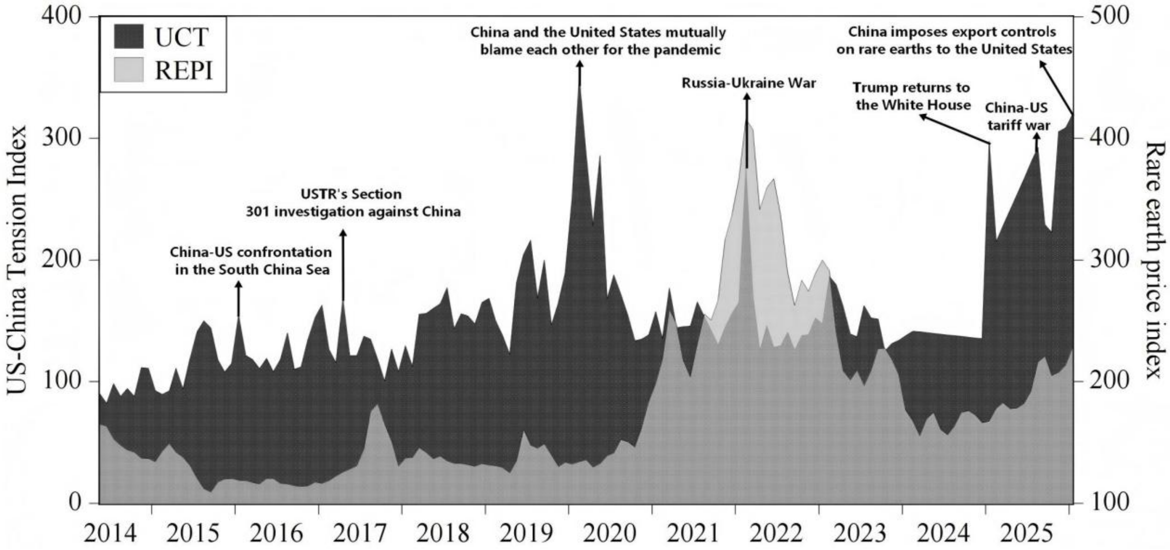


Figure 1. Time trends of variables.

5. Empirical Analysis

This section investigates time-varying causality between RUCT and RREPI via an RB rolling-window procedure. Additionally, it records the changes in the magnitude and direction of the causal effects throughout different sub-periods.

5.1. Full-Sample Granger Causality Test

The empirical strategy relies on a test to capture time-varying Granger-causal effects between RUCT and RREPI. This study set the window length to 12 periods and determine the lag order using the AIC, consistent with Balcilar et al. [35]. The window length is set to 12 and the AIC indicates that the ideal lag order is 1, in accordance with the rolling-window width discussed in Su et al. [40] and Su et al. [41]. The Granger causality full-sample results are displayed in Table 3. Since all of the p-values are higher than 0.10, the null hypotheses cannot be disproved. Both RUCT and RREPI do not Granger-cause each other across the whole sample.

Table 3. Full-sample Granger causality test.

Null hypothesis	Test Statistic	*p*-Value
RUCT does not Granger-cause RREPI	0.543	0.478
RREPI does not Granger-cause RUCT	0.360	0.865

5.2. Parameter Stability Tests

When structural change is present, the parameters of a VAR model may vary over time, potentially biasing full-sample Granger causality test results [42]. Therefore, inference procedures that impose fixed parameters and presume a time-invariant causal link across the entire sample may be incorrect [43]. To assess parameter stability, this study applies the Sup-F, Ave-F, and Exp-F tests proposed by Andrews [44], together with the Lc tests developed by Nyblom [33]. The results show a structural change in the link between RUCT and RREPI, as seen in Table 4, suggesting that full-sample Granger causality inference should be interpreted cautiously.

Table 4. Parameter stability tests for RUCT and RREPI.

	RUCT		RREPI		VAR System	
Test	**Statistic**	**Bootstrap *p*-Value**	**Statistic**	**Bootstrap *p*-Value**	**Statistic**	**Bootstrap *p*-Value**
Sup-F	35.457 ***	0	37.735 *	0.081	23.722 **	0.034
Ave-F	6.082 **	0.025	3.003 *	0.085	4.677 *	0.094
Exp-F	13.599 ***	0	11.908 *	0.073	14.841 **	0.025
Lc					0.802	0.451

Note: *, **, and *** indicate statistical significance at $p < 0.05$, $p < 0.01$, and $p < 0.001$, respectively.

5.3. Sub-Sample Rolling-Window Causality Analysis

Figure 2 summarizes the rolling-window causality results for RUCT and RREPI. Panel (a) displays the p-values of no Granger causality running from RUCT to RREPI, whereas Panel (b) presents the cumulative rolling coefficient estimates. Panels (c) and (d) report the corresponding p-values and cumulative coefficient estimates for the reverse direction (RREPI → RUCT). As indicated in Panel (a), the null of no Granger causality from RUCT to RREPI is denied in three sub-periods: August–October 2022, February–July 2025, and December 2025–January 2026.

Figure 2b indicates that during the first sub-period, RUCT exerts a modest positive effect on RREPI. This effect is closely associated with the signing of the CHIPS and Science Act by the United States in August 2022, which aimed to promote the reshoring of semiconductor manufacturing through tariffs and restrictions on Chinese chips and high-technology products. Considering China's hegemonic role in the world's rare earth supply chain, such policy developments heightened market concerns that China might impose export controls on rare earths—particularly medium and heavy rare earths. These expectations induced precautionary stockpiling by traders and downstream firms, thereby boosting short-term demand and reinforcing medium- to long-term bullish price expectations.

During the second sub-period, RREPI is significantly impacted negatively by RUCT. In February 2025, the U.S. unilaterally imposed additional tariffs on Chinese products, prompting symmetrical retaliatory measures from China and leading to a sustained escalation of bilateral tariffs. This development intensified concerns over a slowdown in global economic growth, thereby dampening demand expectations in downstream rare earth industries. Subsequently, between May and June 2025, the two nations held multiple rounds of consultations in Geneva and London. During these negotiations, the U.S. side lifted restrictions on China, while China correspondingly relaxed certain rare earth export controls, contributing to a recovery in bilateral trade and signaling an easing of trade relations. In July 2025, both sides agreed to a 90-day suspension of selected tariffs. As U.S.–China trade tensions subsided, the impact of RUCT on RREPI turned significantly negative.

In the third sub-period, RUCT again exerts a significant positive effect on RREPI. This episode is primarily associated with heightened geopolitical tensions in late 2025. In December 2025, the U.S. Defense Security Cooperation Agency approved a major arms sales package to Taiwan, followed by China's imposition of sanctions on 27 U.S. defense-related firms. In January 2026, President Trump signed an executive order requiring firms with links to China to divest from U.S. semiconductor assets on national security grounds. In response, China further tightened rare earth export controls, explicitly prohibiting exports of rare earth raw materials and products to overseas military users. Despite U.S. efforts to promote supply-chain "de-Sinicization", technological bottlenecks in rare earth separation and refining prevented rapid substitution. These stringent export controls constrained global supply—particularly of medium and heavy rare earths—triggering concerns over supply-chain disruptions and inducing panic-driven inventory accumulation among European and U.S. firms, thereby driving up short-term demand and prices.

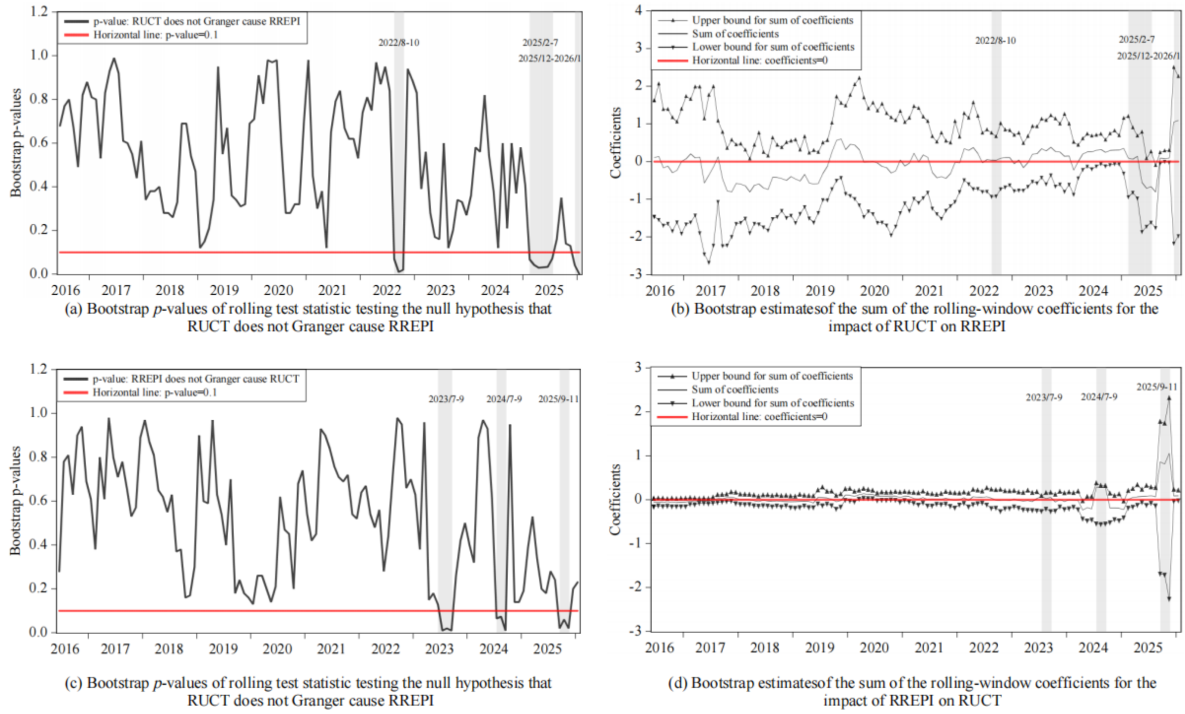
Turning to the reverse direction, Figure 2c demonstrates that the null hypothesis that "RREPI does not Granger-cause RUCT" is also significantly rejected in three sub-periods, namely July–September 2023, July–September 2024, and September–November 2025. This indicates that RREPI serves as a Granger cause of RUCT during these intervals.

Combining Figure 2d with the event context, the first sub-period exhibits a modest positive effect of RREPI on RUCT. In July 2023, Tighter export restrictions on specific rare earth minerals were declared by China's Ministry of Commerce. Given the United States' high dependence on Chinese rare earth supplies, these measures were widely interpreted as an attempt to enhance China's strategic leverage, heightening U.S. concerns over supply-chain security. In August, the United States accelerated policies aimed at diversifying and localizing rare earth supply chains, further intensifying strategic competition in the rare earth sector. By September, global economic recovery strengthened demand across multiple industries, while China's dominant supply position amplified expectations of supply tightness, pushing prices upward. Persistent uncertainty surrounding China's export policy reinforced U.S. policy concerns, thereby strengthening market perceptions of bilateral tension.

During the second sub-period, RREPI exerts a weaker but still positive effect on RUCT. This pattern is primarily attributable to the acceleration of the global green transition in the second half of 2024, particularly the rapid expansion of the electric vehicle industry, which significantly increased demand for rare earths as critical battery and motor materials. U.S. reliance on Chinese supply was further highlighted by China's position as the worldwide largest producer of rare earths, which heightened supply-chain security worries. As U.S. demand for rare earth elements in technology- and green-energy-related industries continued to rise, policy attention to China's rare earth export stance increased, strengthening the positive transmission from RREPI to RUCT.

In the third sub-period, RREPI exhibits a more pronounced positive effect on RUCT. Between September and October 2025, cross-strait tensions escalated following statements by Taiwan's regional leadership. These geopolitical developments quickly influenced supply-chain expectations due to China's preeminence in the international rare earth market, which resulted in significant price swings. At the same time, the Trump administration's assertive foreign policy stance further reinforced the strategic dependence of U.S. defense and semiconductor industries on rare earth inputs, while domestic supply-chain autonomy progressed slowly. In these circumstances, any change to China's export regulations for rare earths greatly increased the unpredictability of the world supply, which increased the benefits of RREPI for RUCT.

Combining (a) and (c), neither RREPI nor RUCT exhibits bidirectional causality during the same time period, and the empirical results are robust.



(a) Bootstrap *p*-values of rolling test statistic testing the null hypothesis that RUCT does not Granger cause RREPI

(b) Bootstrap estimatesof the sum of the rolling-window coefficients for the impact of RUCT on RREPI

(c) Bootstrap *p*-values of rolling test statistic testing the null hypothesis that RUCT does not Granger cause RREPI

(d) Bootstrap estimatesof the sum of the rolling-window coefficients for the impact of RREPI on RUCT

Figure 2. Bootstrap rolling-window Granger causality between RUCT and RREPI.

6. Conclusions

This study utilizes monthly data from June 2014 to January 2026 and implements a bootstrap-based rolling-window causality test to systematically examine the dynamic interaction between U.S.–China tensions (RUCT) and rare earth prices (RREPI). The following is a summary of the primary empirical findings. First, a statistically significant time-varying causal relationship exists between RUCT and RREPI, but such causality emerges only within specific event-driven windows rather than persisting uniformly over time. Second, during August–October 2022—coinciding with the signing of the CHIPS and Science Act in the United States—and December 2025 to January 2026—when U.S. arms sales to Taiwan triggered China's tightening of rare earth export controls—heightened U.S.–China tensions exerted a significant upward effect on rare earth prices by intensifying expectations of supply contraction. In contrast, during February–July 2025, a period characterized by the escalation of the U.S.–China tariff war followed by partial de-escalation, bilateral tensions primarily suppressed rare earth prices by weakening global economic growth prospects and demand expectations. Third, beyond confirming the dominant impact of U.S.–China relations on rare earth prices, the analysis also identifies a reverse feedback mechanism from rare earth prices to bilateral tensions. In several periods, notably in the second halves of 2023, 2024, and 2025, rising rare earth prices amplified U.S. concerns over strategic supply chain vulnerabilities, thereby exerting a weak yet statistically significant effect in further intensifying U.S.–China tensions. These findings indicate that rare earths have evolved from traditional bulk commodities into "geopolitical risk assets", with their price dynamics serving as both reflections of and inputs into great-power strategic competition.

Based on these findings, the paper advances a set of multi-layered policy implications. From China's perspective, policy design should emphasize refined governance and the establishment of long-term institutional mechanisms.

First, it is recommended to establish a national rare earth supply chain risk early-warning and response system. Drawing on time-varying causality frameworks similar to that employed in this study, such a system should integrate indicators of China–U.S. relations, international market sentiment, downstream industrial demand, and domestic production capacity to define multi-tiered warning thresholds. Once triggered, corresponding graded response measures can be activated, allowing policy instruments—such as export controls—to be deployed with greater precision and restraint. This approach would help preserve the credibility and flexibility of strategic deterrence while mitigating excessive market reactions caused by policy uncertainty, thereby reducing cost pressures on key domestic downstream industries, including new energy and electronics.

Second, China should systematically transform its full-spectrum advantages—from resource endowments to processing technologies—into agenda-setting power in global rare earth governance. By taking a leading role in or deeply participating in the formulation of international standards for green production certification, carbon footprint tracing, and responsible sourcing (ESG), China can embed its environmental practices, technological standards, and industrial strengths into global governance frameworks. Initiatives such as international guidelines for sustainable rare earth supply chains or low-carbon rare earth product certification would not only enhance the green premium and compliance-based competitiveness of domestic industries, but also represent a strategic pathway for converting hard power in strategic resources into soft power, thereby shaping international discourse and trade environments in China's favor.

Third, it is imperative to accelerate the establishment of a market-coordinated strategic reserve system for rare earth products, with clearly defined objectives, categories, scales, and transparent rules governing inventory adjustments. Beyond serving as a buffer against extreme supply chain disruptions, such a system should function as a market stabilizer during episodes of abnormal price fluctuations driven by non-fundamental factors. Through countercyclical operations—releasing reserves during irrational price surges and accumulating reserves during excessive downturns—the system can help stabilize prices, safeguard the cost stability and supply security of critical downstream industries, and augment the overall resilience of the rare earth industrial supply chain.

At the industry level, policymakers should encourage leading firms to form long-term strategic alliances with upstream smelting and processing enterprises, supported by supply chain transparency platforms. Instruments such as long-term contracts and cross-shareholding arrangements can strengthen incentive alignment, improve coordination efficiency, and enhance resilience to external shocks. At the international level, China may explore, within multilateral and bilateral frameworks, the establishment of "rare earth supply chain resilience dialogue mechanisms" with major consuming countries. While safeguarding core national interests, such mechanisms could facilitate communication on stabilizing market expectations and avoiding supply chain disruptions, thereby enabling China to shape a more favorable long-term strategic environment within a dynamic geopolitical game.

Author Contributions

Y.H.: conceptualization, methodology, data curation, software, formal analysis, writing—original draft preparation; J.Z.: supervision, validation, writing—reviewing and editing, project administration. Both authors have read and agreed to the published version of the manuscript.

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Use of AI and AI-Assisted Technologies

No AI tools were utilized for this paper.

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