Rare Earth Future Contract Pricing Strategy: Revision on Traditional Commodity Methodology

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Abstract. Rare earth elements (REEs) are essential for advanced technologies like electronics and renewable energy systems, yet their prices fluctuate significantly due to geopolitical uncertainties, particularly China's dominance in production. Despite their economic importance, no active futures markets exist for REEs, leaving stakeholders vulnerable to price risks. This thesis seeks to address this gap by developing a futures pricing model for REEs that accounts for geopolitical influences, adapting the traditional cost-of-carry framework to improve price risk management. The study analyzes the relationship between geopolitical risk and REE spot prices using linear regression, leveraging the Geopolitical Risk (GPR) index and price data from 2015 to 2025. The model adjusts the cost-of-carry approach by incorporating a risk premium derived from regression outcomes and then tests its performance in predicting one-month-ahead futures prices. Findings reveal a significant positive correlation between geopolitical risk and REE prices, confirming that tensions elevate costs. The proposed model achieves reasonable accuracy in stable conditions but struggles during extreme events, such as the 2020 COVID-19 crisis. This tool offers practical value for hedging in typical markets, though future refinements should integrate dynamic risk factors to enhance robustness against sudden shocks.

Keywords: Rare earth futures, Geopolitical risk, Cost-of-carry model

1 Introduction

Rare earth elements (REEs), comprising 17 elements including lanthanides, yttrium, and scandium, are vital for modern technologies such as magnets in electric motors, smartphones, and renewable energy systems. Derivatives, particularly futures contracts, are financial instruments whose value derives from the underlying rare earth prices. Investigations into the availability of rare earth futures contracts revealed ongoing discussions, particularly by the Shanghai Futures Exchange (SHFE), with plans to launch such contracts accelerated as early as 2019. However, as of March 2025, no recent evidence confirms their launch, suggesting that active futures markets for rare earths may not yet exist.

Pricing these derivatives involves forecasting the expected spot price at delivery, adjusted for costs like storage and interest rates. Given the strategic importance of rare

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earths, geopolitical risks, especially from China's dominant production role, significantly impact prices. However specific research on rare earth futures pricing is scarce still. Research suggests that rare earth prices are significantly affected by geopolitical risks, with high risk positively impacting prices due to their strategic value during turmoil. Given the scarcity of direct research on rare earth futures pricing, the approach involves adapting general commodity futures pricing models. The standard model posits that futures prices equal the expected spot price at delivery, adjusted for the cost of carry (storage, interest rates, etc.), potentially modified by convenience yield for commodities withholding benefits. For rare earths, storage costs and convenience yield need specific consideration, given their industrial use rather than holding for yield.

A review by Li et al. focuses on rare earth metal elements, which have a vital strategic role due to wide applications. In electrocatalysis, their unique properties offer great potential. However, systematic reviews are scarce. It thus covers their modified met-al oxides' applications in wastewater treatment, HER, CO_2RR, etc. The electrocatalytic mechanisms and key performance-affecting factors are analyzed, aiming to boost high-performance electrocatalyst development [1]. The study of Depraiter and Goutte delves into the relationship between clean energy markets and geopolitical risk. As the energy transition depends on mineral-intensive clean energy tech, critical minerals like rare earths face geopolitical risk. Using TVP - VAR and Wavelet Coherence, it analyzes links among clean energy indices, rare earth market, and geopolitical risk. Results show geopolitical risk negatively impacts clean energy markets during tensions, with increased connectedness, potentially hampering clean energy investment [2]. Research by Li et al. used the wavelet decomposition technique method to show that the price of rare earth would affect geopolitical risks. Furthermore, after the global pandemic in 2020, there are mutual effects between the two variables. Economic activity also plays a role, with prices rising during high activity and falling during downturns, driven by demand in renewable energy and defense sectors [3]. Guo and Wang's research, using the panel data regression method, construct a rare earth trade dependence network to analyze rare earth trade from 2008 – 2022, revealing expansion and directness. Dependence varies among key countries. Net-work structure impacts prices, with segment-specific influences, followed by some suggestions [4].

The papers of García develop the "theory of transgenic time series" for rare earth oxide price forecasting. Time series are hard to handle due to high - dimensionality. The theory targets metal price cycles and anomalies in time series. By sequencing time series "genomes" and using a defined restriction enzyme, modified time series are created. Results show more accurate short-term forecasts [5]. Forecasting rare earth stock prices is vital but under-researched. Using machine learning, the study of Henriques and Sadorsky finds random forests, etc. outperform Lasso and Naïve Bayes. 10–20-day forecasts via some models exceed 85% and even 90% accuracy sometimes. Key features are identified, and a switching portfolio outperforms [6].

The study of Bayaa and Qadan breaks the U.S. yield curve into level, slope, and curvature factors to analyze its information on the future prices of various commodities. From 1986 to 2021 data, the term structure's shape is informative. Shocks to the level predict positive price and negative volatility changes, while slope and curvature shocks predict negative price changes, mainly post-2004. Findings benefit investors,

policymakers, and mining firms[7]. The paper of Mehrdoust et al. proposes a Markov-switching model for commodity futures and spot dynamics, linking diffusion coefficients and jump size to a hidden Markov chain. It improves existing models by modeling price jumps. Estimating parameters from West Texas Intermediate crude oil spot price via the EM algorithm, it analyzes discretization. It evaluates Euro-pean options under regime-switching, calibrates prices, derives a semi-analytical formula using inverse FT, computes prices with FFT, and derives Greek formulas for risk assessment [8]. In energy volatility forecasting, time variation and persistence of volatility are usually studied separately. Baruník and Vácha's paper presents a new approach enabling shocks with diverse persistence to change smoothly over time, thus modeling both together. Localized regressions identify such dynamics from data. The built model boosts volatility forecasts, outperforming benchmark models, especially for longer horizons [9]. Interest rates are often seen as a key factor for commodity price changes. Yet, their transmission channels are unclear, sparking long debates on rate effects. Empirical studies face difficulties due to complex interactions. To solve this, the competitive storage model is extended to incorporate evolving interest rates, with solution existence and uniqueness conditions set and rate-price interactions analyzed theoretically and quantitatively [10].

As mentioned above, the strategic importance of REEs and the significant influence of geopolitical risks on their prices highlight the need for a specialized approach to pricing rare earth derivatives. The introduction and related research sections have established that rare earth prices are highly sensitive to geopolitical tensions, supply chain vulnerabilities, and demand fluctuations in key industries like renewable energy and defense. However, specific studies on pricing rare earth futures remain limited, necessitating the adaptation of general commodity pricing frameworks to account for these unique dynamics.

The general objective of the research is to develop a pricing model for rare earth futures contracts that integrates geopolitical risks and other market-specific factors, aiming to provide accurate and reliable price forecasts for stakeholders in the rare earth market.

To quantify the impact of geopolitical risks on rare earth prices, the research analyzed historical spot price data alongside geopolitical events, using regression analysis. The model adapts the standard cost-of-carry model for commodity futures pricing by incorporating a geopolitical risk premium and adjusting for rare earth-specific factors, such as low convenience yield due to their industrial use and supply chain constraints, building on foundational commodity pricing theories.

In order to assess the proposed model's performance, futures prices are simulated and compared against historical rare earth spot prices, evaluating accuracy and robustness relative to traditional models like those reviewed in Mehrdoust et al. and Bayaa and Qadan.

Finally, the research targets to offer practical insights and recommendations for market participants on managing price volatility in rare earth markets, leveraging the model's findings to address the strategic and economic implications highlighted in the background.

2 Method

2.1 Adjusting the Spot Price for Geopolitical Risk

The rare earth market is uniquely sensitive to geopolitical events due to the strategic importance of these materials in industries like technology and defense. Unlike traditional commodity pricing models that focus primarily on supply and demand or interest rates, this model explicitly incorporates geopolitical risk through the adjusted spot price. The adjusted expected spot price is defined as:

$$S'(t) = S(t) + \lim_{\|t\|\to 0} E(\beta(GPR_t - GPR_{t-1})|\mathcal{F}_t) \quad (1)$$

where:

S′(t): Adjusted spot price at time t

S(t): Real spot price at time t

β: Regression-derived parameter capturing sensitivity to geopolitical risk changes

GPR: Geopolitical risk index

$\mathcal{F}_t$: Filtration representing all information available up to time t

‖t‖→0: Limit as the time interval between t and t−1 approaches zero.

This term calculates the expected impact of changes in the geopolitical risk index (GPR) on the spot price, conditioned on the filtration $\mathcal{F}_t$, which encapsulates all market information available up to time t. The parameter β, derived from regression analysis, measures the sensitivity of the spot price to geopolitical risk fluctuations. The limit ‖t‖→0 ensures that the adjustment reflects rapid, near-instantaneous responses to geopolitical developments by considering the smallest possible time intervals between t and t−1. This is critical in a market where events such as trade restrictions or policy shifts can cause immediate price volatility.

The use of a conditional expectation introduces a probabilistic approach, recognizing that geopolitical risk effects are uncertain and must be modeled stochastically. This aligns with continuous-time financial models, where prices evolve as stochastic processes adapted to filtration, enhancing the model's theoretical robustness.

2.2 Projecting the Future Price

The future price F(t,T) is calculated using the adjusted spot price S′(t) S'(t) S′(t) within a cost-of-carry framework:

$$F(t,T) = S'(t)e^{(r+u)(T-t)} \quad (2)$$

Here, S′(t) is scaled by the exponential term exp{(r+u)(T - t)}, where r is the risk-free interest rate, u is the storage cost rate and T−t is the time to expiration. This term accounts for the time value of money, a fundamental concept in futures pricing that reflects the cost of holding the asset until the contract expires. The use of continuous compounding (via the exponential function) is a standard practice in financial modeling, ensuring consistency with arbitrage-free pricing principles. To make things easier,

the research applies 3% as a risk-neutral CNY rate and 0.34% storage cost rate, which is referred from other material commodity future storage costs.

By basing F(t, T) on S′(t) rather than S(t), the model embeds geopolitical risk into the future price projection. This modification distinguishes it from traditional cost-of-carry models, which typically exclude such external risk factors, making it particularly suited for rare earth derivatives where geopolitical influences are pronounced. To avoid repeated calibration, the model doesn't apply convenience yield, because rare earth, is a kind of strategic material, whose convenience yield is mainly affected by geopolitical risk issues. The adjusted spot price S′(t) already contains most of it.

3 Results and Discussion

3.1 Linear Regression Analysis of Rare Earth Spot Prices and Geopolitical Risk Index

To investigate the relationship between geopolitical risk and rare earth spot prices, a linear regression analysis was performed using monthly data spanning March 2015 to March 2025. The dependent variable was the average spot price of praseodymium-neodymium oxide (≥99% Nd_2O_3 75%), a key rare earth commodity, sourced from the U.S. Geological Survey (USGS). The independent variable was the Geopolitical Risk Index (GPR), a metric derived from the Federal Reserve that quantifies global geopolitical tensions based on news article analysis. This regression followed an initial attempt using price returns, which proved statistically insignificant, prompting the use of raw spot prices instead.

The regression results reveal a statistically significant positive association between the GPR index and rare earth spot prices. The model produced an R-squared value of 0.204, indicating that 20.4% of the variability in spot prices can be attributed to changes in the GPR index (Table 1). The regression coefficient for GPR was 2.478, with a p-value less than 0.001, suggesting that a one-unit increase in the GPR index corresponds to an average increase of 2.478 units in the spot price of praseodymium-neodymium oxide (Table 2). The overall model significance was robust, with a Significance F value of 2.25E-07, well below the conventional 0.05 threshold (Table 3).

Table 1. General Regression Statistics

Regression Statistics	
Multiple R	0.451617715
R Square	0.20395856
Adjusted R Square	0.197212447
Standard Error	168.6832569
Spotted Value	120

Table 2. Variance Analysis

	Regression Analysis	Residual	Total
df	1	118	119
SS	860264.9419	3357576.858	4217841.8
MS	860264.9419	28454.04117	0
F	30.23348904	0	0
Significance F	2.25097E-07	0	0

Table 3. Coefficients and T-test

	Intercept	X Variable 1
Coefficients	152.7166013	2.478235884
Standard Error	50.87823221	0.450711362
t Stat	3.001609817	5.498498799
P-value	0.003278195	2.25097E-07
Lower 95%	51.96384994	1.585704681
Upper 95%	253.4693526	3.370767087

These findings confirm that geopolitical risk exerts a measurable influence on rare earth prices. For instance, periods of elevated GPR—such as trade disputes or regional conflicts—appear to drive price increases, likely due to perceived threats to supply chains or export restrictions. However, the moderate R-squared value implies that other factors, including supply-demand imbalances, technological developments, or currency fluctuations, also significantly affect price dynamics. This result supports the hypothesis that geopolitical tensions are a critical driver of rare earth market behavior and justifies their inclusion in subsequent futures pricing models. Still, the limited explanatory power highlights the complexity of the market, suggesting a need for a multifaceted approach in future analyses.

3.2 Simulation of Rare Earth Futures Prices Using the Adjusted Cost-of-Carry Model

Building on the insights from Section 3.1, an adjusted cost-of-carry model was developed to simulate futures prices for rare earths, incorporating geopolitical risk. The expected spot price was recalibrated using the formula (1), where S represents the current spot price and β=2.478 is the regression coefficient from the prior analysis. The futures price was then calculated with the formula (2), where r is the risk-free rate (assumed constant 3% for simplicity), u is the storage cost, T=1/12 for a one-month horizon, and similarly with different periods. This simulation covered daily trading data from March 2015 to March 2025.

The general behavior of the model is shown in Fig.1. Futures expired in 1 month and 3 months are predicted. 3-months results may overlap the 1-month future in the chart.

That's because they only have time to expire in difference. So 3 months would be only very little higher than 1 month, which is also close to the real future market.

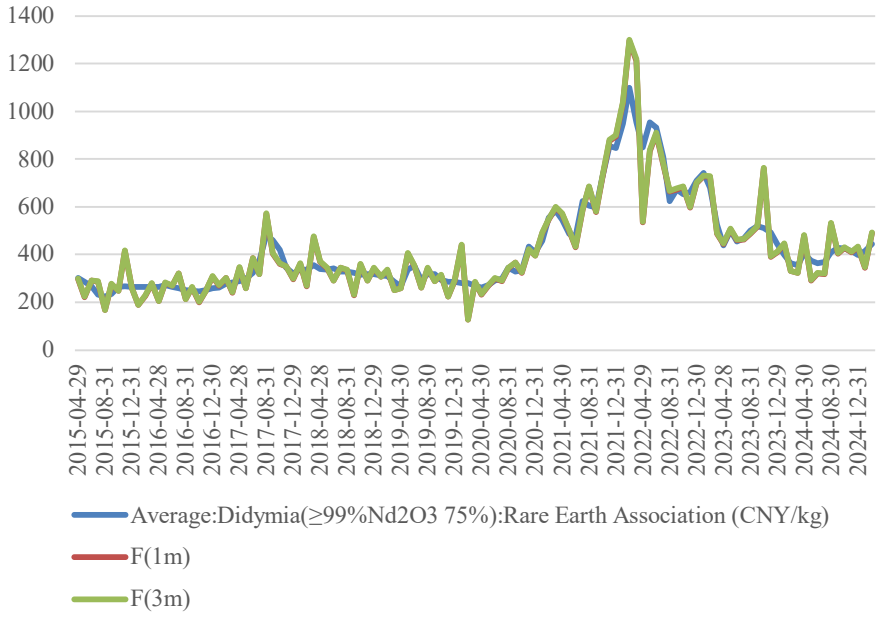

Fig. 1. Predicted future price with expiration of 1 month and 3 months.

To evaluate the model's performance, one-month-ahead simulated futures prices were compared to actual spot prices lagged by one month. The mean absolute error (MAE) across the period was 60.77058 CNY per kilogram, reflecting reasonable predictive accuracy given the inherent volatility of rare earth markets. For example, during 2019—a year marked by the U.S.-China trade war—the model successfully captured an upward price trend, with simulated futures prices ranging from 258.08436 to 403.5793147 per kilogram from April to May, closely aligning with observed spot price movements. This alignment underscores the model's ability to reflect geopolitical influences, such as trade tensions, on market expectations.

Nevertheless, the model faced challenges during periods of extreme volatility. At the beginning of 2020, amidst escalating geopolitical events especially the burst of COVID-19, the predicted futures prices underestimated sharp price spikes, with the MAE of 155.1747197 CNY/kg. This discrepancy suggests that the static incorporation of geopolitical risk via a fixed coefficient may not fully capture sudden market shocks. Enhancements, such as integrating time-varying volatility or event-specific risk indicators, could improve the model's robustness during turbulent conditions.

Overall, the adjusted cost-of-carry model offers a practical framework for simulating rare earth futures prices, particularly in stable market environments. By factoring in geopolitical risk, it provides a more comprehensive approach than traditional models that focus solely on interest rates and storage costs. The simulation results demonstrate

its utility for market participants seeking to anticipate price trends, though its limitations during volatile periods indicate avenues for refinement. Future iterations could incorporate additional variables—like supply chain disruptions or macroeconomic indicators—to enhance predictive accuracy and practical relevance.

4 Conclusion

The thesis has researched the development of a specialized pricing model for rare earth futures contracts, focusing on integrating geopolitical risks into an adjusted cost-of-carry framework. Given the strategic importance of rare earth elements (REEs) and their price sensitivity to geopolitical tensions, the study fills a gap in financial tools for managing price volatility in this market. The main findings reveal a significant positive correlation between geopolitical risk (measured by the GPR index) and rare earth spot prices, with a regression coefficient of 2.478 ($p < 0.001$). Simulations of one-month-ahead futures prices showed reasonable accuracy, with a mean absolute error of 60.77 CNY/kg, though performance weakened during extreme volatility, such as the 2020 COVID-19 onset. These results highlight the model's effectiveness in stable conditions but expose limitations in handling sudden shocks. For policymakers and investors, this model offers a practical approach to price risk management in a geopolitically sensitive market. Future research could enhance its robustness by incorporating dynamic risk adjustments and variables like supply chain disruptions, ensuring better adaptability to volatile conditions and broader applicability.

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