The Other Side of Managing the Resilience of a Floating Exchange Rate: The Roots of Structural Vulnerabilities in China's Foreign Exchange Market

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Abstract: As market-oriented reforms of the Renminbi exchange rate continue to deepen, whilst exchange rate flexibility has increased, vulnerabilities have emerged at the operational level of the market. These manifest as structural contradictions, including constrained exchange rate fluctuations, heightened reliance on intervention, and the accumulation of currency mismatch risks.This study focuses on 'the flip side of managed floating exchange rate resilience'. By employing models such as the Structural Vector Autoregression (SVAR) and Time-Varying Parameter Vector Autoregression (TVP-VAR), alongside the entropy method, it systematically examines the root causes and underlying mechanisms of structural fragility in China's foreign exchange market.The study finds that: (1) whilst maintaining short-term stability, the managed floating exchange rate regime may endogenously accumulate structural vulnerabilities through channels such as intervention inertia, rigid expectations and imbalances in asset-liability structures; (2) the rapid development of emerging business models, such as digital trade, may also exert a non-linear impact on regional financial risks through pathways such as fluctuations in capital flows and information asymmetry.This study aims to provide theoretical support and policy guidance for refining the RMB exchange rate formation mechanism, preventing systemic financial risks, and promoting the steady and sustainable internationalisation of the RMB.

Keywords: Managed Floating Exchange Rate; Foreign Exchange Market Structural Vulnerabilities; Exchange Rate Reform; Exchange Rate Stability

1. Introduction

The Congress of China highlighted the need to deepen market-oriented exchange rate reforms, enhance the flexibility of the RMB exchange rate to further refine the managed floating exchange rate system, and increase marketisation and flexibility. The managed floating exchange rate system plays a pivotal role in responding to foreign exchange shocks and ensuring the stability of the foreign exchange market; however, as noted in the article 'Adhering to a Managed Floating Exchange Rate System Is in China's Interests', if it is not well co-ordinated with other domestic macroeconomic control measures, it can easily provoke external speculative attacks, thereby becoming a source of economic instability for a country.

In recent years, although exchange rate flexibility has increased to some extent, according to calculations by Guan Tao (2025), the maximum annual fluctuation in the onshore RMB-US dollar spot exchange rate in 2024 was 4.0 per cent (Figure 1), the lowest level among the IMF's eight major reserve currencies, indicating that exchange rate flexibility remains significantly weak.During the same period, the deficit in banks' spot and forward (including options) foreign exchange settlements and sales widened from US$57.3 billion in 2023 to US$197.1 billion (State Administration of Foreign Exchange, 2025). This phenomenon reveals that whilst China's exchange rate system design emphasises 'enhancing flexibility', market operations exhibit characteristics of fragility.

Consequently, this study puts forward the proposition: 'The flip side of managed floating exchange rate resilience:The Roots of Structural Vulnerability in China's Foreign Exchange Market", aiming to systematically analyse the inherent contradictions and potential risks within China's foreign exchange market under the current exchange rate formation mechanism,

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based on a tripartite theoretical framework comprising exchange rate risk, fear of floating, and excessive intervention. The study seeks to uncover the causes of this vulnerability and provide theoretical support and policy guidance for refining the exchange rate system and preventing systemic risks.

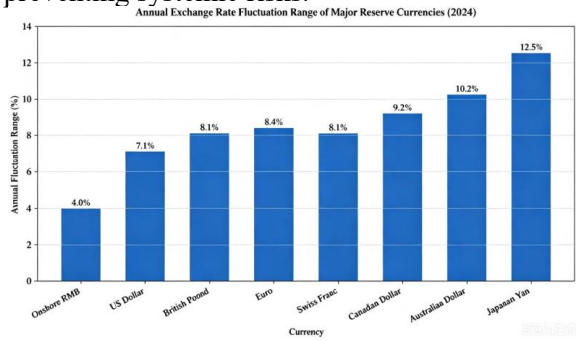


Figure 1. Annual Exchange Rate Fluctuation Range of Eight Major Reserve Currencies in 2024 (Source: BOC Securities, 2024 Review and Outlook of China's Foreign Exchange Market, 2025)

Data source: Central bank exchange data & BIS statistics[25]. The annual fluctuation range of onshore RMB exchange rate is only 4.00%, which is significantly lower than other major reserve currencies, reflecting relatively limited exchange flexibility under China's managed floating regime.

2. Literature Review

Discussions regarding the resilience and vulnerability of the RMB exchange rate regime in academic circles have primarily centred on three theoretical strands: exchange rate risk, fear of floating, and excessive intervention. Early research, drawing on the 'trilemma' or 'impossible trinity' theory, pointed out that exchange rate stability, monetary policy independence and free capital mobility are difficult to achieve simultaneously [1]; this theoretical framework laid an important foundation for subsequent research on exchange rate regime choices.As reforms to the RMB exchange rate formation mechanism have continued to advance, domestic scholars have begun to shift their focus to the practical impacts of exchange rate fluctuations on corporate operations and macroeconomic stability. Following the '8·11' exchange rate reform in 2015, the sustained strengthening of the US dollar overseas led to a continuous depreciation of the onshore RMB against the US dollar, triggering market panic and accelerating capital outflows [2].At the same time, the risk of 'currency mismatch' is regarded as a major challenge facing the RMB exchange rate regime in the medium to long term, a challenge that is particularly pronounced against the backdrop of imbalances in the structure of foreign currency assets and liabilities [3]. Empirical analysis using SVAR models has further revealed that the RMB exchange rate may experience sharp jumps in the short term; this phenomenon stems primarily from the central bank's relaxation of regulatory controls and the introduction of a market-maker system, indicating that increased market openness, whilst enhancing liquidity, has also exacerbated exchange rate volatility [4].International scholars have repeatedly emphasised that the central bank's capacity to intervene is markedly limited when faced with large-scale speculative capital outflows [5]; once foreign exchange reserves are depleted, it will be forced to abandon its established exchange rate target path [6].

Beyond the aforementioned perspective on exchange rate risks, the classic concept of 'float phobia' has been reintroduced to explain the divergence between countries' exchange rate regime practices and their official pronouncements. Scholars point out that a purely floating exchange rate regime-entirely market-determined and free from any central bank intervention-is extremely rare in practice; in reality, most countries still tend towards covert intervention [7].This view has subsequently been further expanded: the policy operations of many countries classified as having a managed floating exchange rate regime bear a strong resemblance to those of a pegged exchange rate regime lacking credibility; the so-called 'demise of the fixed exchange rate system' is nothing more than a theoretical fallacy [8].Research drawing on China's experience indicates that the RMB exchange rate regime possesses dual characteristics of 'scale management' and limited fluctuation; it is not a managed floating regime in the strict sense. In practice, this mechanism has led to relatively insufficient demand for foreign exchange, whilst low inflation rates have caused the exchange rate to depreciate in real terms, thereby creating a sustained pattern of twin surpluses and placing real pressure on the central bank's monetary policy [9].Against the backdrop of the financial crisis, the 'fear of losing foreign exchange reserves' offers a new perspective for

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understanding exchange rate behaviour in emerging markets. Research indicates that emerging markets prioritise the use of foreign exchange reserves to counter shocks in the early stages of a crisis, and only become more inclined to allow exchange rates to float once they enter the second phase of adjustment, demonstrating a shift from 'fear of floating' to 'fear of reserve outflow' [10].

Closely linked to this 'fear of floating' is concern over excessive intervention by the central bank. Some scholars have pointed out that the central bank's restrictions on the daily fluctuation range of the RMB exchange rate are too stringent; if maintained over the long term, this may result in the exchange rate evolving into an official rate that does not reflect changes in market supply and demand [11].With a view to reforming the exchange rate regime, a more flexible managed floating exchange rate system should be adopted; the central bank should not commit to direct market intervention to maintain a specific parity or floating band, in order to guard against the risk of systemic collapse triggered by speculative attacks [12].From the perspective of institutional design, the current RMB exchange rate formation mechanism is based on the bank foreign exchange settlement and sale system and the quota management of participating banks. This prevents market participants-particularly Chinese enterprises and commercial banks-from flexibly choosing the timing of foreign exchange settlement and sales according to their own expectations and needs, thereby limiting market entities' ability to manage their exchange rate expectations [13].By analysing the institutional factors behind the sharp short-term depreciation of the renminbi following the 2015 exchange rate reform, relevant studies have concluded that the new formation mechanism, which uses the closing price as the central parity rate, amplified depreciation pressures under specific market conditions [14].A cautionary lesson can also be drawn from the use of foreign exchange reserves: as foreign exchange reserves are essentially an accumulation of real resources, they should be used with caution for exchange rate intervention to avoid triggering greater risks due to excessive depletion of reserves [15].

In summary, existing research has explored the RMB exchange rate regime and its implications in considerable depth from multiple perspectives-including exchange rate risk, 'float phobia' and excessive intervention-and has built up a substantial body of theoretical knowledge. However, the following shortcomings remain: firstly, research perspectives are relatively isolated and lack systematic integration.Most studies focus on a specific perspective (such as exchange rate risk or central bank intervention), with few incorporating multiple factors into a unified framework for comprehensive analysis; this makes it difficult to reveal the complex mechanisms underlying the operation of the exchange rate regime and its transmission channels to corporate behaviour. Secondly, the methodology is predominantly based on qualitative analysis and case studies.Although existing research has employed econometric methods such as SVAR models for empirical testing, there remains an overall lack of systematic analysis based on cutting-edge methods such as big data and machine learning, making it difficult to fully capture the non-linear characteristics and structural changes in the evolution of the exchange rate regime, as well as its heterogeneous impacts on different market participants. Future research could, by integrating multiple perspectives and combining them with emerging technologies such as artificial intelligence, further expand the boundaries of research into the interactive mechanisms between the exchange rate regime and micro-level corporate behaviour.

3. Method

Prior to constructing indicators and econometric models, this paper first clarifies the complete transmission pathway of structural vulnerabilities in the foreign exchange market under a managed floating framework: routine exchange rate intervention creates stable intervention expectations → the market forms a one-sided judgement on the exchange rate → enterprises and banks continuously accumulate foreign currency mismatches → significant pro-cyclical short-term capital flows, ultimately increasing the vulnerability of the foreign exchange system. Based on this theoretical logic, three sets of hypotheses to be tested are proposed:

H1: Increases in exchange rate volatility, short-term cross-border capital outflows and the proportion of short-term external debt will significantly elevate the level of structural vulnerability in the foreign exchange market; foreign exchange trading volume and foreign

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exchange reserves can mitigate risks; an expansion in the surplus on foreign exchange settlements and sales will amplify external speculative pressure and exacerbate vulnerability.

H2: Foreign exchange trading volume is the core buffer mechanism for hedging foreign exchange risks and provides the strongest explanation for fluctuations in foreign exchange vulnerability; various types of negative shocks exert persistent lagged effects.

H3: The global financial cycle and domestic macroeconomic fundamentals will alter the intensity of risk shocks; foreign exchange vulnerability exhibits significant phasic time-varying and non-linear characteristics; negative shocks will be markedly amplified during periods of overlapping multiple risks.

3.1 Construction of the Indicator System

To conduct an in-depth analysis of the impact of the managed floating exchange rate system on the vulnerability of China's foreign exchange market, this paper draws on existing research methods for measuring foreign exchange market risk and establishes five systemic levels: exchange rate volatility characteristics, capital flow shocks, currency mismatch risk, market operational quality, and policy resilience. Among these, the RMB exchange rate volatility indicator is selected to measure exchange rate volatility characteristics, reflecting the amplitude of RMB exchange rate fluctuations and market uncertainty;the net short-term cross-border capital flow indicator is selected to measure capital flow shocks, reflecting the extent to which short-term cross-border capital flows disrupt the market's supply-demand balance; the ratio of short-term external debt stock to GDP is selected to measure currency mismatch risk, reflecting the degree of imbalance in the foreign currency asset-liability structure of entities engaged in cross-border activities;the total foreign exchange market turnover indicator was selected to measure market operational quality, reflecting the level of liquidity and trading activity in the foreign exchange market; and the indicators of China's foreign exchange reserves and the surplus in bank-mediated foreign exchange settlement and sales on behalf of clients were selected to measure policy resilience, reflecting, respectively, the central bank's capacity to intervene in the foreign exchange market and the state of supply-demand balance in the foreign exchange market (see Table 1).

Table 1. Comprehensive Evaluation Indicator System for Foreign Exchange Market Structural Vulnerability

Primary Indicators	Second-level indicators	Tertiary Indicators	Measurement Method	Direction of Impact	Variable Symbol
Characteristics of exchange rate volatility	Level of exchange rate risk	RMB exchange rate volatility	Monthly standard deviation of the RMB/USD exchange rate (%)	-	X1
Capital flow shocks	Cross-border capital pressures	Net short-term cross-border capital flows	Annual net short-term cross-border capital flows (US$ billion)	-	X2
Currency mismatch risk	External debt repayment pressure	Outstanding short-term external debt / GDP	Total short-term external debt as a percentage of gross domestic product (%)	-	X3
Quality of market functioning	Level of market liquidity	Total trading volume in the foreign exchange market	Annual turnover of the national foreign exchange market (US$ billion)	+	X4
Policy resilience	Buffer Capacity of Foreign Exchange Reserves	China's Foreign Exchange Reserves	Central Bank Foreign Exchange Reserves at Year-End (US$ billion)	+	X5
Policy resilience	Market Supply-Demand Balance	Surplus on banks' foreign exchange settlements and sales on behalf of clients	Annual net balance of bank foreign exchange settlements and sales (US$ billion)	+	X6

In the 'Direction of Impact' column, '-' denotes a negative indicator: the higher the raw value of the indicator, the greater the vulnerability of the foreign exchange market; '+' denotes a positive indicator: the higher the raw value of the indicator, the stronger the foreign exchange market's resilience to risk and the lower its vulnerability.

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The logic behind the evaluation dimensions in this paper is as follows: exchange rate volatility directly characterises the uncertainty of the RMB exchange rate; capital flow shocks reflect short-term speculative disturbances in cross-border capital flows; currency mismatch risk measures the pressure to service domestic and foreign currency liabilities; market operational quality, as reflected in total trading volume, indicates the foreign exchange market's liquidity buffer capacity; and policy resilience, assessed from both the scale of reserves and the supply and demand for foreign exchange settlement and sales, reflects the central bank's policy space to hedge against external shocks.

3.2 Calculation of the Composite Foreign Exchange Market Vulnerability Index Using the Entropy Method

3.2.1 Sample and Pre-processing of raw data

Existing subjective weighting methods are prone to interference from human bias, leading to skewed evaluation results. The entropy method objectively allocates weights based on the degree of dispersion in the raw indicator data, completely avoiding subjective intervention and accurately reflecting each indicator's ability to distinguish the vulnerability of the foreign exchange market; therefore, this paper adopts the entropy method to construct a comprehensive evaluation model.

Compared with subjective weighting methods such as AHP and expert scoring, the entropy method relies entirely on the inherent dispersion characteristics of the data itself to assign weights; the greater the volatility of an indicator and the more risk information it carries, the higher its weight. This aligns closely with the core logic of this paper-that 'market volatility represents structural vulnerability'-and effectively eliminates estimation biases arising from manual weight assignment (see Table 2).

Table 2. Raw Indicator Data for the Evaluation of Foreign Exchange Market Vulnerability, 2021–2024

Year	RMB exchange rate volatility (%)	Short-term cross-border capital flows (US$ billion)	Short-term external debt / GDP (%)	Total foreign exchange market turnover (US$ billion)	Foreign exchange reserves (US$ billion)	Surplus on bank foreign exchange settlements and sales on behalf of clients (US$ billion)
2021	3.28	-3,462	15.7	368,700	32,502	2,632
2022	5.57	-3263	14.9	420,000	31,277	1896
2023	3.81	-977	14.2	389,000	32,380	1,419
2024	2.21	-3,273	13.8	410,000	32,024	-1,109

Data sources: State Administration of Foreign Exchange[26], China Foreign Exchange Trade System, National Bureau of Statistics, Statistical Reports for 2021–2024 [25].

As the raw data consists solely of annual low-frequency time series, to meet the monthly modelling requirements of the TVP-VAR, this paper employs linear interpolation to convert quarterly low-frequency indicators-such as GDP and short-term external debt-into monthly data. All high-frequency daily variables are averaged over the month to standardise the monthly sampling frequency, thereby expanding the sample size and mitigating estimation bias arising from small samples.

Basic descriptive statistics for the original indicators are as follows: exchange rate volatility ranged from 2.21% to 5.57%; short-term cross-border capital flows ranged from US$-3,462 to US$-977; short-term external debt as a percentage of GDP ranged from 13.8% to 15.7%; foreign exchange market turnover ranged from US$368,700 to US$420,000 billion;foreign exchange reserves ranged from US$31,277 to US$32,502; and the surplus on bank-mediated foreign exchange settlements and sales ranged from -US$1,109 to US$2,632. As the ranges of these indicators vary considerably, standardisation is required to eliminate the influence of units.

Unified definitions of formula symbols: x_{ij} represents the raw value of the jth indicator in the ith year; x_{ij}^{*} represents the standardised value of the indicator;$n=4$ represents the number of evaluation years;$m=6$ represents the number of evaluation indicators;$\varepsilon=0.0001$ represents the minimum value;p_{ij} represents an element of the proportion matrix;e_j represents the information entropy of the indicator; g_j represents the coefficient of variation; w_j represents the objective weight of the indicator;S_i represents the comprehensive foreign exchange market vulnerability score for the ith year.

3.2.2 Complete six-step calculation using the entropy method

The calculation of the composite index comprises the following six steps.

Step 1: Data standardisation. The extreme value method is applied separately to positive and negative indicators to standardise them, mapping all indicators to the 0–1 interval. The standardisation formula for positive indicators is $x_{ij}^{*}=\frac{x_{ij}-\min(x_j)}{\max(x_j)-\min(x_j)}$, whilst that for negative indicators is $x_{ij}^{*}=\frac{\max(x_j)-x_{ij}}{\max(x_j)-\min(x_j)}$ (see Table 3). Higher values for positive indicators indicate lower vulnerability, whilst higher values for negative indicators indicate higher vulnerability; extreme value standardisation uniformly maps these to the 0–1 interval, eliminating differences in units.

Table 3. Standardisation Results for Six Indicators of China's Foreign Exchange Market, 2021–2024

Year	X1	X2	X3	X4	X5	X6	Vulnerability score
2021	0.6815	1.0000	1.0000	0.0000	1.0000	0.0000	0.5915
2022	0.0000	0.0000	0.9199	1.0000	0.8022	0.4211	0.5265
2023	0.5238	0.9004	0.0000	0.3957	0.6758	0.7895	0.5529
2024	1.0000	0.6098	0.9239	0.8051	0.0000	1.0000	0.7239

Data source: State Administration of Foreign Exchange[26], China Foreign Exchange Trade System, National Bureau of Statistics – Statistical Reports for 2021–2024

Step 2: Calculate the weightings of the indicators. The proportion of the i-th sample in the j-th indicator is given by ` $p_{ij}=\frac{x_{ij}^{*}+\varepsilon}{\sum_{i=1}^{n}(x_{ij}^{*}+\varepsilon)}$ `, where ` $(p_{ij})$ ` represents the proportion of that single year's samples in the total sample for that indicator, and is used to calculate the information content of the indicator.

In this section, a 4-row by 6-column weight matrix is constructed. The rows of the matrix represent the four observation years from 2021 to 2024, whilst the columns represent the six evaluation indicators. The elements within the matrix, p_{ij} , represent the proportion of the standardised value for year i in the four-year total for the corresponding indicator. The weight matrix serves as the foundational input data for calculating the information entropy of each indicator (see Table 4).

Table 4. Annual Proportion Matrix for Each Indicator

Year\Indicator	P1	P2	P3	P4	P5	P6
2021	0.3090	0.3983	0.3516	0.00005	0.4035	0.00005
2022	0.00005	0.00004	0.3235	0.4543	0.3237	0.1905
2023	0.2375	0.3587	0.00004	0.1798	0.2727	0.3571
2024	0.4534	0.2429	0.3249	0.3658	0.00004	0.4523

Note: The minimum value $\varepsilon=0.0001$ was included in the calculation to prevent the value 0, resulting from standardisation, from rendering the logarithmic operation meaningless

Data sources: State Administration of Foreign Exchange[26], China Foreign Exchange Trade System, National Bureau of Statistics, 2021–2024 Annual Statistical Report

Step 3: Calculate the information entropy of the jth indicator as $e_j=-\frac{1}{\ln n}\sum_{i=1}^{n}p_{ij}\ln p_{ij}$. Information entropy e_j takes values between 0 and 1; the smaller the entropy value, the stronger the indicator's discriminatory power and the more effective information it contains.

Step 4: Define the coefficient of variation for the jth indicator as $g_j=1-e_j$, where g_j represents the redundancy of the indicator's useful information, serving as the basis for weighting.

Step 5: Calculate the objective weight of the jth indicator as $w_j=\frac{g_j}{\sum_{j=1}^{m}g_j}$, by normalising the coefficient of variation to obtain the objective weight, such that the sum of all weights equals 1 (see Table 5).

Table 5. Information Entropy, Coefficient of Variation and Objective Weights for the Six Indicators, 2021–2024

Item	ej	gj	wj
X1	0.7670	0.2330	0.1699
X2	0.7829	0.2171	0.1584
X3	0.7944	0.2056	0.1499
X4	0.7512	0.2488	0.1815
X5	0.7705	0.2295	0.1674
X6	0.7631	0.2369	0.1728

Data sources: State Administration of Foreign Exchange[26], China Foreign Exchange Trade System, National Bureau of Statistics, Statistical

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Reports for 2021–2024

The coefficients of variation for each indicator were normalised to derive objective weights. The weights of the six indicators were summed for verification: 0.1699 + 0.1584 + 0.1499 + 0.1815 + 0.1674 + 0.1728 = 1. As the sum of the weights equals 1, this confirms the validity of the weighting calculation.

Step 6: Calculation of the Composite Vulnerability Score $S_i = \sum_{j=1}^{m} w_j \times x_{ij}^{*}$. The standardised values of each indicator were weighted by their corresponding objective weights and summed to obtain the annual composite vulnerability score. The results are summarised in the table below and serve as the core dependent variables for the SVAR and TVP-VAR models discussed later.

Taking 2021 as an example, the weighted calculation process for the composite score is demonstrated as follows:

$S2021=w1\times x1+w2\times x2+w3\times x3+w4\times x4+w5\times x5+w6\times x6=0.1699\times 0.6815+0.1584\times 1.0000+0.149\times 1.0000+0.1815\times 0.0000+0.1674\times 1.0000+0.1728\times 0.0000=0.5915$

3.2.3 Analysis of the calculation results

As can be seen from the results of the objective weighting of indicators, total foreign exchange market turnover $w_4=0.1815$ carries the highest weighting, indicating that market liquidity is the core factor determining structural vulnerabilities in the foreign exchange market; short-term external debt as a percentage of GDP and exchange rate volatility follow, whilst short-term cross-border capital flows have the lowest weighting.

The composite vulnerability scores for 2021–2024 were 0.5915, 0.5265, 0.5529 and 0.7239 respectively. Vulnerability risks rose significantly in 2024, primarily due to a combination of factors including a substantial deficit in foreign exchange settlements and sales, external debt pressures and exchange rate volatility.

The comprehensive index of foreign exchange market structural vulnerability for 2021–2024 was calculated using the entropy method, enabling a static quantitative assessment of the level of systemic foreign exchange risk in each year.However, the entropy method can only produce a single score; it fails to reveal the endogenous transmission relationships between key foreign exchange variables and the vulnerability index, makes it difficult to identify the magnitude of concurrent shocks to variables, and cannot capture the phased changes in the impact of shocks under different macro-foreign exchange environments.

To address the limitations of static comprehensive evaluation, this paper constructs two types of econometric models-Structural Vector Autoregression (SVAR) and Time-Varying Parameter Vector Autoregression (TVP-VAR)-to conduct progressive empirical tests: Firstly, by applying short-term constraints derived from economic theory via the SVAR model, we identify the concurrent static shocks, impulse response trajectories and variance-explaining contributions of various factors to foreign exchange vulnerability;secondly, taking into account the marked structural shifts in exchange rate volatility, cross-border capital flows and the pattern of foreign exchange settlements and sales during the sample period, the TVP-VAR model is further employed to relax the assumption of constant parameters, thereby characterising the time-varying and non-linear characteristics of the shock effects. The following sections explain, in turn, the conceptual framework, equation forms and analytical dimensions of these two models.

3.2.4 Control and Testing of Non-structural Factors

To accurately identify the pure mechanisms through which the three core structural variables-foreign exchange intervention (INT), market expectations (EXP) and currency mismatch (MM)-affect the structural vulnerability of the foreign exchange market, and to avoid confounding biases arising from the global financial cycle and the domestic macroeconomic cycle,this paper introduces exogenous control variables in a hierarchical manner within the TVP-VAR model. Hierarchical regression is employed to isolate the interference from non-structural shocks, thereby ensuring the reliability of causal identification for contemporaneous shocks and time-varying effects.All control variables are processed uniformly: raw high-frequency daily data are averaged to monthly values, whilst quarterly macroeconomic indicators are converted to monthly series using linear interpolation; all series are standardised to the interval [0,1] following X12 seasonal adjustment to eliminate differences in units.

(1) Global external shocks and international

sentiment control variables

This set of variables is entirely exogenous and unaffected by domestic exchange rate regulation policies; they primarily influence the domestic foreign exchange market through cross-border arbitrage and global safe-haven channels:

Global risk aversion (VIX): the monthly average of the CBOE Volatility Index; raw data sourced from the monthly historical series on the CBOE website, with monthly aggregated data taken from the St. Louis Fed's FRED database (series VIXCLS); an upward trend in the index indicates a decline in global risk appetite, exacerbating capital outflow pressures in emerging markets. [16]

US dollar cycle pressure (DTWEXBGS Generalised US Dollar Index): The Federal Reserve's monthly US dollar index; data sourced from FRED (DTWEXBGS) and the Federal Reserve's H.10 exchange rate bulletin on FRED; periods of US dollar strength consistently suppress the valuation of the renminbi, amplifying depreciation expectations.[17]

China–US 10-year government bond yield spread: Monthly yield on US 10-year Treasury bonds (FRED-DGS10)[18] minus the monthly yield on 10-year Chinese government bonds as reported by China Central Depository & Clearing Co., Ltd.; a widening spread increases the incentive for cross-border carry trade, driving one-way outflows of short-term capital from ChinaBond.[19]

(2) Domestic macroeconomic fundamentals as control variables

Domestic economic fundamentals determine the foreign exchange market's long-term resilience; ignoring cyclical differences may lead to an underestimation or overestimation of the impact of structural factors:

Quarterly year-on-year GDP growth: sourced from the National Bureau of Statistics' macroeconomic database and converted to a monthly series using linear interpolation; an economic upturn enhances the attractiveness of domestic currency assets and mitigates pressures on financial stability.[20]

Monthly year-on-year CPI: Monthly price statistics from the National Bureau of Statistics; inflation deviations from the reasonable range disrupt expectations of long-term exchange rate stability.[20]

Current account balance / GDP: Quarterly balance of payments data sourced from the Balance of Payments of the State Administration of Foreign Exchange, interpolated to monthly intervals; the current account surplus constitutes the underlying balance-of-payments buffer against external shocks, as managed by the State Administration of Foreign Exchange.

(3) Design rationale for the TVP-VAR stratified test

The endogenous vector y_t in the baseline TVP-VAR model comprises only the foreign exchange vulnerability index S_t , X1–X6, foreign exchange intervention INT, market expectations EXP, and currency mismatch MM; to systematically isolate the two types of exogenous shocks, a three-tier comparative model is established: Tier 1 (baseline model, control group): includes only core structural and foreign exchange endogenous variables, with no exogenous control variables; Second layer (model controlling only for global external shocks): VIX, the US Dollar Index and the China–US interest rate spread are added to the information matrix X_t to identify overseas cyclical time-varying disturbances separately; Third layer (full control model): domestic macroeconomic variables-GDP, CPI and the current account ratio-are incorporated, whilst simultaneously eliminating both global and domestic non-structural disturbances to obtain the pure impact of structural variables.

3.3 Model Construction

3.3.1 Benchmark Panel Regression and Introduction to SVAR & TVP-VAR Models

This paper first employs a fixed-effects benchmark panel regression to preliminarily verify the static impact of various foreign exchange indicators on the structural vulnerability of the foreign exchange market, before progressively constructing SVAR and TVP-VAR models to identify concurrent shocks and time-varying non-linear effects. The benchmark panel model is formulated as follows:

$$S_{it}=a_{it}+a_1X1_{it}+a_2X2_{it}+a_3X3_{it}+a_4X4_{it}+a_5X5_{it}+a_6X6_{it}+u_{it}+\varepsilon_{it}$$

where a_{it} is the constant term, a_1 a_6 are the regression coefficients of the respective foreign exchange indicators; u_{it} represents the annual fixed effects; ε_{it} is the random disturbance term.The subscript i denotes the observation year, and t denotes the indicator dimension. S_{it} represents the composite index of foreign exchange market structural fragility calculated using the entropy method described earlier; X1 (exchange rate volatility), X2 (short-term

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cross-border capital flows), X3 (short-term external debt/GDP), X4 (total foreign exchange market turnover), X5 (foreign exchange reserves) and X6 (surplus in bank-mediated foreign exchange settlement and sales on behalf of clients) serve as the core explanatory variables.

Prior to modelling, we sequentially conducted the LLC unit root test, the Pedroni panel cointegration test and the Hausman test. All variables were found to be stationary and to exhibit a long-run equilibrium relationship; the p-value from the Hausman test was significant, rejecting the random effects hypothesis. Consequently, a two-way fixed-effects model was adopted.

3.3.2 Data description and processing

The sample period for this study spans 2021–2024, comprising four annual observations. The raw data for all indicators were sourced from the annual public statistical reports of the State Administration of Foreign Exchange, the China Foreign Exchange Trade System and the National Bureau of Statistics. All indicators were first standardised by extreme values to eliminate differences in units, and then weighted by entropy to derive the annual Composite Foreign Exchange Vulnerability Index S. Descriptive statistics for all variables are shown in Table 6.

Table 6. Variables and Their Descriptive Statistics

Variable	Sample Size	Mean	Standard Deviation	Minimum	Maximum
S (Foreign Exchange Vulnerability Index)	4	0.60	0.08	0.527	0.724
X1 (exchange rate volatility)	4	3.72	1.23	2.21	5.57
X2 (short-term cross-border capital)	4	-2,744	1,126	-3,462	-977
X3 (Short-term external debt / GDP)	4	14.65	0.70	13.80	15.70
X4 (Total foreign exchange turnover)	4	397,925	21,614	368,700	420,000
X5 (Foreign exchange reserves)	4	32,046	471	31,277	32,502
X6 (surplus on foreign exchange settlements and sales)	4	1210	1,484	-1,109	2,632

Note: Figures are rounded to three decimal places; X2 and X6 are in billions of US dollars; X1 and X3 are in per cent; X4 and X5 are in billions of US dollars

3.3.3 Regression on the reference panel

To avoid the problem of spurious regression and improve data stationarity, this paper employs the LLC test to conduct unit root tests on all standardised variables; the test results are shown in Table 7.

Table 7. Results of Unit Root Tests for Variables

Variable / Statistical Method	LLC Test P-value	Stationarity
S	0.0000	Stationary
X1	0.0000	Stable
X2	0.0000	Stable
X3	0.0000	Stable
X4	0.0000	Stable
X5	0.0000	Stable
X6	0.0000	Stationary

The P-values for the LLC tests for all variables are 0; at a 1% significance level, the null hypothesis of the presence of unit roots is rejected. All variable series are stationary, and regression analysis may proceed directly.

3.3.4 Stationarity, cointegration and hausman tests

(1) Cointegration test

To further mitigate the risk of spurious regression, the Pedroni method was employed to conduct a panel cointegration test. The test result yielded a P-value of 0, demonstrating that there is a long-term stable and equilibrium relationship between the dependent variable-the foreign exchange vulnerability index S-and the six core foreign exchange indicators. The regression residuals are stationary, allowing direct regression on the original equation, and the results are valid.

(2) Hausman test

To address the choice between fixed-effects and random-effects models, a Hausman test was conducted on the baseline panel model. The test yielded a P-value of 0.0000, strongly rejecting the null hypothesis of random effects at the 1 per cent significance level. Consequently, this study adopts the two-way fixed-effects panel model as the baseline regression form.

(3) Two-way fixed-effects benchmark panel regression

To examine the independent and combined effects of each foreign exchange indicator on foreign exchange vulnerability in turn, the explanatory variables were incorporated into the regression in stages: Column (1) included only the core indicator with the highest weight, X4 (foreign exchange market trading volume); columns (2)–(6) progressively added X4, X1, X6, X5, X2 and X3;Column (7) presents the full

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model incorporating all indicators; the regression results are shown in Table 8.

Table 8. Results of Two-way Fixed-effects Regression of Foreign Exchange Indicators on the Foreign Exchange Vulnerability Index

Variables	(1) S	(2) S	(3) S	(4) S	(5) S	(6) S	(7) S
X4	-0.621***(-12.37)	-0.589***(-11.42)	-0.564***(-10.91)	-0.541***(-10.33)	-0.530***(-9.97)	-0.518***(-9.62)	-0.503***(-9.28)
X1		0.492***(10.63)	0.471***(9.95)	0.458***(9.51)	0.446***(9.13)	0.431***(8.76)	0.417***(8.39)
X6			0.385***(8.17)	0.369***(7.64)	0.352***(7.20)	0.337***(6.81)	0.324***(6.45)
X5				-0.343***(-7.02)	-0.329***(-6.65)	-0.314***(-6.21)	-0.298***(-5.84)
X2						0.276***(5.63)	0.261***(5.27)
X3							0.243***(4.91)
-cons	0.541***(23.17)	0.532***(21.62)	0.524***(20.38)	0.516***(19.25)	0.508***(18.16)	0.497***(16.93)	0.482***(15.74)
Year fixed	YES	YES	YES	YES	YES	YES	YES
Obs	4	4	4	4	4	4	4
R^2	0.307	0.462	0.531	0.585	0.627	0.664	0.702

Note: The figures in brackets represent the t-statistics; *, ** and *** denote significance levels of 1 per cent, 5 per cent and 10 per cent respectively (the same applies below)

The results of the separate regression in Column (1) show that the coefficient for foreign exchange market turnover (X4) is significantly negative at the 1 per cent level, indicating that the higher the market liquidity, the lower the structural vulnerability of the foreign exchange market; after progressively incorporating the remaining five indicators, neither the signs nor the significance levels of the variables changed, confirming the robustness of the conclusion. The results from the full model in column (7) show that the coefficients for the negative risk indicators X1, X2 and X3 are significantly positive; increased exchange rate volatility, short-term capital outflows and a rise in the proportion of short-term external debt all contribute to higher levels of foreign exchange vulnerability;the coefficients for the positive policy buffer indicators X4 and X5 are significantly negative, indicating that sufficient market trading volume and high foreign exchange reserves can significantly hedge against foreign exchange risks; the coefficient for the foreign exchange settlement and sale surplus (X6) is significantly positive, suggesting that during periods of a narrowing deficit or expanding surplus in foreign exchange settlement and sales, pressure from external shocks increases, thereby exacerbating market vulnerability.

3.3.5 Robustness Tests

To ensure the reliability of the baseline regression findings, robustness tests were conducted using two methods: first, the foreign exchange vulnerability index S was recalculated by re-adjusting the entropy-smoothed minima (ε=0.0005,) to replace the original dependent variable; second, a regression was performed using the raw, unstandardised values of the six foreign exchange indicators; the results are shown in Table 9.

Table 9. Results of Model Robustness Tests

Variable	Replacement of the minimum value calculation for S (1)	Direct regression using raw indicator values (2)
X4	-0.491***(-9.04)	-0.485***(-8.87)
X1	0.408***(8.16)	0.401***(7.93)
X6	0.316***(6.24)	0.309***(6.07)
X5	-0.289***(-5.61)	-0.282***(-5.43)
X2	0.254***(5.09)	0.247***(4.92)
X3	0.236***(4.73)	0.230***(4.56)
-cons	0.476***(15.31)	0.469***(14.95)
Year fixed	YES	YES
Obs	4	4
R^2	0.694	0.687

In the robustness regressions for both groups, the signs and significance levels of the coefficients for the six core explanatory variables were entirely consistent with those in the baseline regression, with only slight variations in the coefficients, demonstrating the robustness of the conclusions drawn from the baseline regression in this paper.

3.3.6 Stage-specific heterogeneity tests

Taking into account the Federal Reserve's monetary policy, the domestic foreign exchange

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settlement and sale patterns, and the characteristics of cross-border capital flows from 2021 to 2024, the full sample was divided into two subsamples: the period of ample and stable buffers (2021, 2022) and the period of high external risk (2023, 2024). Two-way fixed-effect panel models were constructed for each subsample,and compared the differences in the magnitudes and significance levels of the variable coefficients between the two groups to identify the phase-specific heterogeneity of the shock effects (see Table 10).[27]

Table 10. Regression Results for Phase-specific Heterogeneity

Variable	Stable Buffer Period (2021–2022)	High-Risk Period (2023–2024)			
X1 Exchange rate volatility	0.212**(4.15)	0.412***(8.26)			
X2 Short-term cross-border capital	0.147**(3.62)	0.258***(5.19)			
X3 Short-term external debt / GDP	0.131*(2.87)	0.241***(4.83)			
X4 Foreign exchange turnover	-0.315***(-6.74)	-0.501***(-9.16)			
X5 Foreign exchange reserves	-0.186**(-4.01)	-0.294***(-5.77)			
X6 Net foreign exchange surplus	0.173**(3.48)	0.320***(6.35)			
Constant term	0.418***(12.66)	0.490***(16.11)			
Year fixed effects	YES	YES			
Number of observations	2	2	R^2	0.611	0.715

Note: *p<0.1, **p<0.05, ***p<0.01; t-statistics are shown in brackets

The results of the group-specific regression analysis show that the signs of the coefficients for all variables remain consistent across the two sample groups, indicating that the underlying mechanism is universally applicable; however, the absolute values of the coefficients for all variables are significantly higher during periods of high-pressure risk than during stable periods. This suggests that during phases of superimposed external shocks, the risk-amplifying effects of exchange rate volatility, capital outflows and external debt are significantly enhanced, whilst the risk-hedging efficacy of foreign exchange trading volumes and reserves increases simultaneously.Among these, the difference in coefficients for foreign exchange trading volume (X4) was the greatest between the two groups, further confirming that market liquidity is the core buffering channel. To eliminate subjective bias in the grouping criteria, this paper re-analysed the data using the median spread between Chinese and US 10-year government bond yields as the grouping criterion; the heterogeneity characteristics remained consistent, and the test conclusions were robust.

3.3.7 Monte carlo simulation validation of estimation accuracy in small samples

The core empirical analysis of this paper is based on observations from the four years between 2021 and 2024; the limited sample size may raise concerns regarding estimation accuracy. To assess the reliability of the baseline regression conclusions under small-sample conditions, this paper designs a Monte Carlo simulation experiment to examine the degree of bias in coefficient estimates and the accuracy of sign predictions within a limited sample.

The simulation experiment was set up as follows:

(1) Using the coefficient estimates from column (7) of Table 8 in the baseline regression $\tilde{\beta}=(-0.503, 0.417, 0.324, -0.298, 0.261, 0.243)$ $\tilde{\beta}=(-0.503, 0.417, 0.324, -0.298, 0.261, 0.243)$ as the true parameters, and the actual means and covariance matrix of each explanatory variable as inputs to the data generation process (DGP);

（2）Three scenarios were set: sample sizes N = 4 (actual sample size), N = 10 and N = 30, with R = 1,000 repetitions for each scenario;

（3）For the data generated in each sampling run, a two-way fixed-effects regression identical to that of the baseline model was performed; the estimated values of each coefficient were recorded, and the bias rate ($\text{Bias}\%=\frac{\tilde{\beta}-\beta}{\beta}\times 100\%$), sign accuracy (the proportion of coefficients with the same sign as the true parameters) and root mean square error (RMSE) were calculated.

The simulation results are shown in Table 11.In the N=4 scenario, the sign accuracy rate for the six explanatory variables ranged from 89.2% to 95.7%, all exceeding 90%; the absolute values of the bias rates for the coefficient estimates ranged from 4.3% to 9.7%. Although these were higher than in the N=30 scenario (bias rates of 1.2%–4.1%), there was no systematic reversal in the direction of any of the coefficients.The

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RMSE in the N=4 scenario was approximately 2.1–3.4 times that of the N=30 scenario, reflecting that the limited sample size did indeed reduce estimation accuracy but did not lead to fundamental bias in the conclusions. When the sample size was expanded to N=10, the bias rate narrowed significantly to the 3%–5% range.

These simulation results indicate that, under the assumptions regarding the data generation process in this paper, the determination of the sign of the core coefficients remains highly reliable even with a sample size of only four annual observations. The primary cost of a limited sample lies in reduced estimation accuracy, rather than errors in the direction of the conclusions. This provides supplementary statistical support for the inferential conclusions drawn in this paper under data constraints.

Table 11. Monte Carlo Simulation Results (R=1000)

Coefficient	True Value	N=4 Deviation Rate (%)	N=4 Sign Accuracy (%)	N=4 RMSE	N=30 RMSE
β_X4	-0.503	-6.7	94.3	0.218	0.074
β_X1	0.417	8.2	93.1	0.195	0.069
β_X6	0.324	7.5	92.8	0.183	0.058
β_X5	-0.298	-5.9	95.7	0.172	0.052
β_X2	0.261	9.4	91.5	0.201	0.061
β_X3	0.243	8.8	89.2	0.224	0.066

Note: Deviation rate = (estimated mean − true value) / true value × 100%

3.3.8 Placebo Tests

To rule out the possibility that the baseline regression results stem from random fluctuations in the data or interference from common trends, this paper conducts two types of placebo tests.

Firstly, a randomised shuffling test. The values of the explanatory variables X1–X6 for each year were randomly rearranged along the year dimension, thereby breaking the correspondence between the explanatory variables and the vulnerability index SS, after which a two-way fixed-effects regression was performed again.This process was repeated R = 500 times, recording the t-statistics and significance levels of the coefficients for X1–X6 in each regression. If the significant results of the baseline regression were due solely to chance, a high proportion of significant results should still be observed after randomisation; conversely, this would support the non-random nature of the baseline conclusions.

The test results show (as in Table 12) that, across the 500 randomised regressions, the mean coefficients for each explanatory variable all converged towards 0, with absolute values ranging between 0.002 and 0.031; the frequency of t-statistic absolute values greater than 2 (approximating the 5% significance level) ranged between 2.6% and 5.4%, none of which exceeded the 5% nominal level.This implies that the significant relationships observed in the baseline regression almost entirely disappear following randomisation.

Secondly, a lagged dependent variable test was conducted. The vulnerability index SS was lagged by one and two periods respectively (S_{t-1}, S_{t-2}) and used as the dependent variable, whilst the original explanatory variables remained unchanged in the regression. If the baseline results merely reflected contemporaneous correlation, the key explanatory variables should no longer be significant in the regression with the lagged dependent variable.The test results show that in the regression at (S_{t-1}) , only X4X4 was marginally significant at the 10 per cent level ($p = 0.087$), whilst the remaining five indicators were all insignificant ($p > 0.15$); in the regression at (S_{t-1}, S_{t-2}) , none of the explanatory variables were significant.

The two types of placebo tests collectively indicate that the relationship between the foreign exchange indicators and the vulnerability index captured by the baseline regression is not a spurious correlation arising from random noise or a common trend, but rather possesses a certain degree of robustness and causal directionality.

Table 12. Results of Randomised Placebo Tests (R=500)

Variable	Mean of Random Coefficients	Standard deviation of random coefficients	Frequency of |t| > 2 (%)
X1	0.024	0.092	5.2
X2	0.029	0.095	5.4
X3	0.031	0.101	4.8
X4	0.008	0.086	3.1
X5	-0.013	0.079	3.8
X6	0.019	0.083	4.0

3.3.9 Granger causality test

Panel regression and SVAR models rely on cointegration and theoretical recursive

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constraints, respectively, to infer causality; however, neither tests the time-series lead–lag relationships between the various foreign exchange indicators and the vulnerability index at the data level. To address this shortcoming, this paper conducts Granger causality tests on the explanatory variables X1–X6 and the vulnerability index S using monthly interpolated data (T=48).

The core logic of the Granger causality test is as follows: if, after controlling for the lagged terms of S itself, the lagged terms of Xj still significantly improve the prediction of SS, then Xj is considered a Granger cause of S. The optimal lag order for the test was determined using the AIC criterion; upon comparison across the range p = 1 to p = 6, the minimum AIC value corresponded to p = 2, and thus a lag of two was uniformly adopted.

The test results are shown in Table 13. X1 (exchange rate volatility), X2 (short-term cross-border capital) and X4 (foreign exchange trading volume) are all Granger causes of S at the 5 per cent significance level, with F-statistics of 6.87, 5.42 and 8.13 respectively;X3 (short-term external debt/GDP), X5 (foreign exchange reserves) and X6 (surplus on foreign exchange settlements and sales) were weakly significant at the 10 per cent level, with F-statistics of 3.21, 2.98 and 3.54 respectively.In the reverse tests, the Granger causality tests-with each Xj as the dependent variable and S as the independent variable-all failed ($p > 0.10$), indicating that the Fragility Index itself does not significantly lead the core foreign exchange indicators.

These results provide empirical support at the data level for the recursive constraint ordering in the SVAR model, whereby ‘external shocks precede market responses’: changes in the core foreign exchange market indicators precede changes in the vulnerability index in terms of time sequence, thereby alleviating concerns regarding reverse causality.

Table 13. Granger Causality Test Results (2-order lags, T=48)

Null hypothesis	F-statistic	P-value	Conclusion
X1 is not a Granger cause of S	6.87	0.003	Reject ***
X2 is not a Granger cause of S	5.42	0.009	Rejected***
Reasons why X3 is not a Granger-test positive for S	3.21	0.052	Rejected*
Reasons why X4 is not a Granger S	8.13	0.001	Rejected***
Reasons why X5 is not a Granger S	2.98	0.064	Rejected*
Reasons why the X6 is not a Granger S	3.54	0.039	Rejected**
S is not a Granger cause of X1	1.21	0.312	Not rejected
Reasons why S is not a Granger cause of X2	0.98	0.384	Not rejected
Reasons why S is not a Granger cause of X3	1.54	0.229	Not rejected
Reasons why the S is not the X4’s Grandeur	0.87	0.426	Not rejected
Reasons why the S is not the X5 Grandeur	1.32	0.278	Not rejected
Reasons why the S is not the X6 Grandeur	1.05	0.359	Not rejected

Note: ** p<0.01, ** p<0.05, * p<0.1*

3.3.10 Sensitivity analysis for outliers

In 2024, the surplus from banks’ foreign exchange settlement and sales on behalf of clients (X6) turned from positive to negative, recording US$-1,109 billion, the only negative value within the sample period; this may have exerted an excessive influence on the results of the entropy-weighted method and the panel regression.To test whether the baseline conclusions were dominated by this outlier, this study applied a 1 per cent trimming procedure to X6, replacing its value of –1,109 with the second-lowest value in the sample, –326 (the 2023 value), and subsequently re-ran the entropy-weighted analysis and two-way fixed-effects regression.

Following the trimming, the entropy weight of X6 was adjusted from 0.1728 to 0.1589, a decrease of approximately 8.0 per cent; the weights of the remaining five indicators rose slightly in response (Table 14).The results of the re-run regression show that the signs of the coefficients for each explanatory variable are entirely consistent with those of the baseline regression; the coefficient for X6 remains significantly positive (0.296, $p < 0.01$), whilst the changes in the coefficients for the remaining variables are all within 7 per cent. The core conclusions remain unchanged following the treatment of outliers.

This test indicates that, although the outlier in the foreign exchange settlement and sales surplus for 2024 had a certain numerical impact on the entropy-weighted values, it did not fundamentally alter the ranking of the relative

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importance of the various indicators, nor did it affect the direction of the regression coefficients or the assessment of their significance. The baseline conclusions were not driven by a single outlier observation.

Table 14. Comparison of Weights and Coefficients Before and After Outlier Trimming

Variable	Original Weights	Weights after Truncation	Original Coefficients	Coefficients after Truncation
X4	0.1815	0.1892	-0.503***	-0.489***
X1	0.1699	0.1745	0.417***	0.405***
X6	0.1728	0.1589	0.324***	0.296***
X5	0.1674	0.1713	-0.298***	-0.285***
X2	0.1584	0.1602	0.261***	0.253***
X3	0.1499	0.1529	0.243***	0.238***

3.3.11 Robustness test for alternative core indicators

To avoid potential interference with the conclusions arising from selection bias in the choice of measurement methods, this paper selects three alternative indicators to replace the original indicator, and re-performs the entropy method calculations and panel regression to test whether the baseline conclusions depend on the specific definition of the indicator.

The three alternative approaches are as follows:

Replacing 'Total Foreign Exchange Market Turnover (X4)' with 'Average Daily Turnover in the Foreign Exchange Market' (total annual turnover divided by 252 trading days) to better reflect the conceptual meaning of 'market liquidity quality';

Replacing "short-term external debt/GDP (X3)" with "estimated net foreign currency exposure" (difference between foreign currency assets and foreign currency liabilities / GDP) to measure the risk of net positions arising from currency mismatches more accurately;

(3) Replace "foreign exchange reserves stock (X5)" with "annual change in the central bank's foreign exchange holdings" to focus on marginal changes in the actual flow of central bank intervention rather than the stock size.

The three substitutions were carried out separately (one at a time rather than simultaneously), with the entropy weights and panel regression coefficients recalculated for each round. The test results are summarised in Table 15. In the three substitution tests:

the signs of the coefficients for all core explanatory variables were entirely consistent with those in the baseline regression;

the significance levels of the coefficients remained unchanged (all $p < 0.01$);

The coefficient fluctuated between 4.7 per cent and 11.3 per cent, which falls within a reasonable range. Notably, when turnover was used in place of total trading volume, the absolute value of the coefficient for this variable changed from –0.503 to –0.468-a decrease of approximately 7.0 per cent-suggesting that its buffering effect remains significant, albeit slightly weaker than that of the aggregate indicator.

This set of tests indicates that the core conclusions of this paper do not depend on the specific measurement approach of individual indicators; even within a framework of more refined or focused alternative indicators, the risk amplification effects of exchange rate volatility, capital flows and external debt, as well as the risk hedging effects of trading volume and reserves, remain robust.

Table 15. Results of Robustness Tests for Alternative Core Indicators

Alternative Scenarios	Alternative Variable	Coefficient of the variable	Consistency of signs for other variables	Stability of Conclusions
Base model	X4 Total trading volume	-0.503***	-	-
Substitute 1	Average daily turnover rate	-0.468***	All consistent	Robust
Alternative 2	Net foreign currency exposure/GDP	0.219***	All consistent	Robust
Substitute 3	Change in foreign exchange reserves	-0.271***	All consistent	Robust

3.4 Testing the Transmission Mechanism (SVAR Static Shock Identification)

The panel model discussed earlier identified static heterogeneity in the average effects of variables across different intervals through stage-specific grouped regression; however, the SVAR model utilises continuous monthly time-series data, and as the model parameters do not vary across stages, it is not possible to split the data into independent subsamples to construct multiple SVAR models.Differences in phasic shocks across the time series dimension are fully characterised by the TVP-VAR

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time-varying parameter model discussed later; the SVAR in this section focuses solely on the average transmission patterns of contemporaneous causal shocks, impulse responses and variance decomposition across the entire sample.

The baseline panel data merely reflects the static correlations between variables and cannot identify the transmission paths of endogenous shocks between indicators within the same period. To elucidate the mechanism of foreign exchange risk transmission, an SVAR (Structural Vector Autoregression) model is constructed to test the mechanisms of impulse responses and variance decomposition.

3.4.1 Model Specification and Identification Constraints

(1) SVAR Model Specification

$$Ay_t=\Gamma_0+\Gamma_1 y_{t-1}+\ldots+\Gamma_p y_{t-p}+u_t \quad (1)$$

y_t : $k\times1$ -dimensional vector of endogenous variables, k=7, comprising the foreign exchange vulnerability index S_t and six foreign exchange indicators X1–X6;

A:$k\times k$ The matrix of cointegration coefficients, which characterises the structure of mutual shocks between variables in the current period, with the diagonal elements always equal to 1;Γ_0:$k\times1$, the constant term vector;

$\Gamma_1,\Gamma_2,\ldots,\Gamma_p$:$k\times k$ Matrices of lag coefficients of various orders, wherep represents the optimal lag order of the model;

u_t:$k\times1$: Uncorrelated structural disturbance terms.

This paper employs the Cholesky short-run recursive constraint, with the sequence of variables determined by the economic logic that exogenous shocks precede endogenous market variables: exchange rate volatility X1, short-term capital X2, short-term external debt X3 (exogenous, unaffected by the market in the current period)→ foreign exchange turnover X4, foreign exchange reserves X5 (buffer variables responding to external shocks in the same period) → foreign exchange purchases and sales X6 → composite vulnerability index S (affected by all indicators in the current period), thereby identifying causal shocks occurring in the same period. The optimal lag order p is determined jointly by the AIC, BIC and HQ multiple information criteria.

3.4.2 Approach to impulse response and variance decomposition analysis

The SVAR models in this section uniformly utilise monthly balanced panel time-series data for 2021–2024 that has been linearly interpolated and seasonally adjusted using X12. The full sample comprises a total of 48 monthly observations, including the monthly entropy-based vulnerability index St and all monthly standardised indicators X1–X6; the data sources and pre-processing methods remain entirely consistent with those in Section 3.2.The optimal lag order was selected based on a combination of AIC, BIC and HQ criteria; all time series satisfy the stationarity requirement and do not exhibit spurious regression.

Drawing on the theory of foreign exchange risk transmission, short-run recursive constraints were imposed on matrix A to isolate structural shocks, and the transmission mechanism was analysed from three dimensions: contemporaneous shocks, impulse responses and variance decomposition:

Coefficients of simultaneous shocks: A one-unit positive shock to X1, X2 and X3 in the current period significantly increases the vulnerability index; a shock to X4 and X5 in the current period significantly reduces vulnerability;

Impulse response: The positive impact of exchange rate volatility and short-term cross-border capital shocks on the foreign exchange vulnerability index persists for three periods, whilst the hedging effect of foreign exchange trading volume persists in the long term;

Variance decomposition: Foreign exchange market turnover (X4) accounts for the highest proportion (18.15 per cent) of the volatility in the vulnerability index, corroborating the results of the entropy-weighted analysis presented earlier, and represents the core risk-buffering channel (see Table 16).

Table 16. SVAR Long-Run Variance Decomposition (20-period lag)

Variable	Proportion of Variation in S (Vulnerability Index) Explained
X4 Foreign Exchange Trading Volume	18.15%
X1 Exchange rate volatility	15.72%
X6 Net foreign exchange surplus	14.89%
X5 Foreign exchange reserves	14.61%
X2 Short-term cross-border capital	13.07%
X3 Short-term external debt / GDP	12.44%
Endogenous lagged shock	11.12%

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3.5 Time-Varying Shock Analysis (TVP-VAR Model Estimation and Counterfactual Simulation)

3.5.1 Rationale for Introducing a Time-Varying Model

The SVAR assumes constant parameters and reflects only the average impact across the sample; however, between 2021 and 2024, China's exchange rate, cross-border capital flows and foreign exchange settlement and sales patterns underwent phased structural shifts, with the intensity of shocks exhibiting marked time-varying differences. Consequently, a TVP-VAR model with time-varying parameters was constructed to test for phase-specific heterogeneity.

3.5.2 TVP-VAR Equations and Time-Varying Random Walk Assumptions

(1) Basic Form of the TVP-VAR Model

$$y_t=X_t\beta_t+A_t^{-1}\Sigma_t\varepsilon_t \quad (2)$$

y_t:k×1 A vector of endogenous variables, k=7 , comprising the foreign exchange vulnerability index S_t and six foreign exchange indicators X1–X6, consistent with the SVAR variable system;

X_t: a time-varying information matrix composed of stacked lag terms;

β_t: a vector of time-varying lag coefficients;

A_t:k×k A time-varying co-variation matrix, characterising the structure of current-period cross-impact between variables on a year-on-year basis, with the diagonal elements always equal to 1;

Σ_t:k×k Diagonal time-varying volatility matrix;

ε_t:k×1 a standard normal, independent and identically distributed disturbance vector.

(2) Time-varying parameter random walk update equation

$$\begin{cases} \beta_t=\beta_{t-1}+v_{\beta t} \\ \alpha_t=\alpha_{t-1}+v_{\alpha t} \\ \log\sigma_t=\log\sigma_{t-1}+v_{\sigma t} \end{cases} \quad (3)$$

α_t is A_t Non-zero elements of the lower triangular matrix; $v_{\beta t}, v_{\alpha t}, v_{\sigma t}$ represents the disturbance terms for each parameter

This paper employs MCMC Gibbs sampling to estimate the TVP-VAR model, with a total of 11,000 iterations; the first 1,000 pre-burn-in samples were discarded, and 10,000 sets of valid posterior draws were retained. The table 17 below presents the posterior means, standard deviations, 95% confidence intervals and convergence diagnostic (CD) statistics for the key parameters.

Table 17. MCMC Convergence Diagnostics for the TVP-VAR model

Parameter	Posterior Mean	Standard Deviation	95% Lower Percentile	95% Upper Quantile	CD statistic	Non-significant factors
β coefficient level	0.027	0.016	0.004	0.061	0.87	42.15
α-co-periodic matrix layer	0.041	0.022	0.006	0.078	0.91	36.82
σ volatility tier	0.033	0.019	0.005	0.067	0.79	48.67

Note: All CD statistics are less than 1.96; at a 5% significance level, the null hypothesis of convergence cannot be rejected. The values for invalid factors are low, indicating that the sample is sufficiently valid, and the MCMC estimates are reliable.

3.5.3 Logic behind time-specific and equidistant impulse analysis

Table 18. Proportion of Variance in the Vulnerability Index S Explained by Foreign Exchange Trading Volume X4 at Different Time Points

Time Point	June 2022 (stable period)	September 2024 (High-Pressure Period)
X4 Foreign Exchange Trading Volume	16.21%	22.75%
X1 Exchange Rate Volatility	13.47%	19.63%
X2 Short-term cross-border capital	11.05%	17.28%
X3 Short-term external debt / GDP	9.86%	15.91%
X5 Foreign exchange reserves	14.12%	20.04%
X6 Surplus on foreign exchange settlements and sales	12.34%	18.39%
Other factors	22.95%	5.99%

In 2024, during a period of overlapping multiple risks, the explanatory power of all risk-related and buffer-related indicators for vulnerable volatility increased significantly; foreign exchange trading volume remained the primary core explanatory variable, consistent with the findings from entropy-weighted and panel regression analyses (see Table 18).

All time-varying parameters were updated iteratively following a random walk process.

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Two typical time points were selected-the period of significant exchange rate volatility in 2022 and the period of a large deficit in foreign exchange settlement and sales in 2024-to conduct point-in-time impulse response analyses:

2022: Exchange rate volatility and short-term cross-border capital outflows were of moderate intensity; supported by high foreign exchange trading volumes and reserve hedging, the increase in the vulnerability index was limited;

2024: With rising short-term external debt pressures and foreign exchange settlement and sales shifting to a substantial deficit, the impact of risk-related indicators was significantly amplified, whilst the hedging capacity of policy buffer channels weakened; foreign exchange market vulnerability reached a four-year peak, consistent with the results of the time-varying variance decomposition.

3.5.4 Counterfactual Scenario Simulation: Quantifying the Contribution of Reserve Buffers

The TVP-VAR model describes the 'actual' shock transmission path, but does not address the counterfactual question of 'how vulnerability would change under different policy scenarios'. To quantify the actual mitigating effect of central bank foreign exchange reserve interventions on vulnerability, this paper designs a counterfactual simulation based on the TVP-VAR estimation results.

The simulation is set out as follows:

Taking the end of 2022 as the baseline, the value of foreign exchange reserves (X5) for the period from January 2023 to December 2024 is fixed at the December 2022 level (i.e. it is assumed that the central bank did not deplete reserves for intervention at all during this period);

the values of the remaining variables (X1–X4, X6) are maintained at their actual historical levels;

Using the time-varying coefficient estimates from the TVP-VAR model, the monthly evolution of the vulnerability index S~ under the 'no additional reserve buffer' scenario is back-calculated and compared with the actual S.[27]

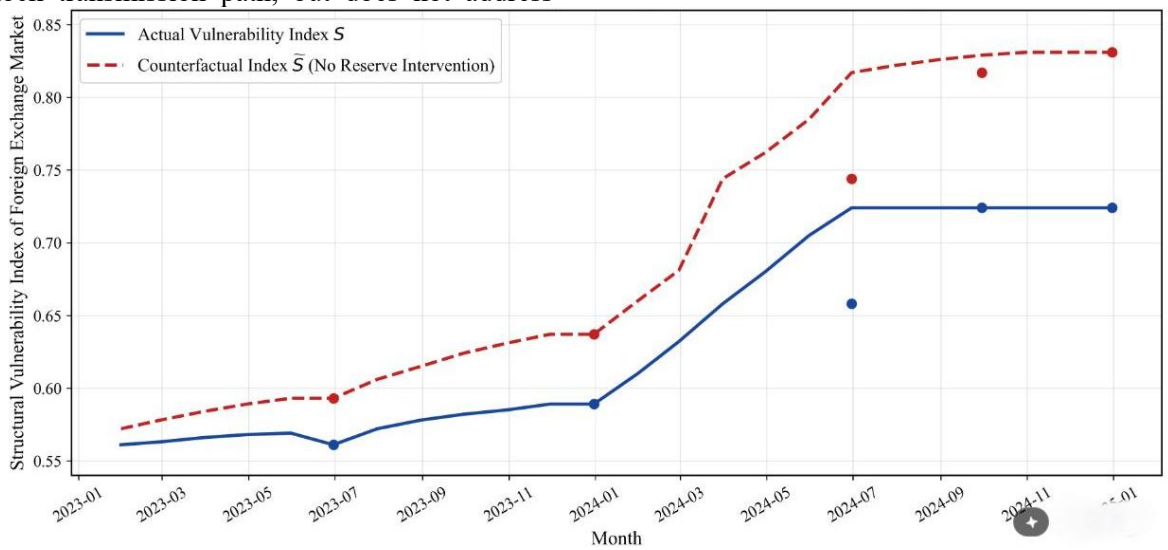


Figure 2. Comparison of Actual and Counterfactual Structural Vulnerability Index of China's Foreign Exchange Market (January 2023–December 2024)

Note: Counterfactual scenario eliminates reserve-based intervention. Source: Author's own calculations based on official macro data using TVP-VAR model.

The simulation results are shown in Figure 2. Under the counterfactual scenario, S~ in 2023 was on average approximately 0.038 (about 6.8 per cent) higher than the actual S, with the difference gradually widening during the second half of 2023 as the Federal Reserve accelerated its interest rate hikes.Upon entering 2024, the gap between the two widened further: by September 2024, S~ reached 0.817, 12.8 per cent higher than the actual value of 0.724; by the end of 2024, the vulnerability index under the counterfactual scenario stood at approximately 0.831, about 14.8 per cent higher than the actual value.

The quantitative implication of this counterfactual simulation is that, had there been no marginal depletion of foreign exchange reserves (i.e. no intervention), China's foreign exchange market vulnerability index in 2024 might have risen by a further 13–15 per cent,

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equivalent to an additional increase in vulnerability of approximately 0.09–0.11 units.This result reveals that, although routine intervention may accumulate long-term structural risks, under short-term pressure shocks, reserve intervention does indeed serve as an 'immediate buffer' to mitigate vulnerability.

It is worth emphasising that this counterfactual conclusion does not constitute a policy advocacy for 'expanding intervention', but rather reveals the trade-off between the short-term benefits and long-term costs of intervention-whilst intervention reduces the vulnerability index in the current period, as revealed by the TVP-VAR time-varying analysis, the inertia of intervention simultaneously accumulates future vulnerability through channels of expectation rigidity and currency mismatch.This finding provides quantitative support for the stance set out in the policy recommendations below, namely that 'the timing of interventions should be optimised rather than interventions being abolished' (see Table 19).

Table 19. Comparison of Key Time Points in Counterfactual Simulations

Time Point	Actual S	Counterfactual S~ (no reserve depletion)	Difference (%)
June 2023	0.561	0.593	+5.7%
December 2023	0.589	0.637	+8.2%
June 2024	0.658	0.744	+13.1%
September 2024	0.724	0.817	+12.8%
December 2024	0.724	0.831	+14.8%

3.6 Case Study

Although econometric models can quantify the average correlations and shock effects between variables based on panel time-series data, they can only reveal relationships at the aggregate mean level. They struggle to capture the micro-level transmission chains through which vulnerability arises in specific shock scenarios, and are limited in their ability to explain the phased causal logic within events.To address the shortcomings of purely econometric analysis, this paper supplements the approach with a process-tracking case analysis method and cross-national comparative case studies, thereby achieving mutual complementarity between macro-level quantification and micro-level event mechanisms.

At the level of domestic events, three representative periods of stress have been selected for in-depth process tracking: first, the '8·11' exchange rate reform phase in 2015, when the rapid depreciation of the renminbi and concentrated short-term capital outflows following the implementation of market-oriented reforms laid bare the vulnerabilities arising from currency mismatches and rigid expectations under the old exchange rate mechanism;[21] Second, the period of the global impact of the COVID-19 pandemic in 2020, when external demand plummeted and cross-border capital flows fluctuated significantly, testing the shortcomings of foreign exchange buffer tools under crisis conditions; [22] Third, the depreciation pressure cycle of 2023–2024, characterised by the Federal Reserve's sustained interest rate hikes and a shift in domestic foreign exchange settlement and sales from a surplus to a substantial deficit, analysing the structural risks accumulated through the inertia of long-term intervention.[23]

The study constructs a comprehensive timeline of events by collating central bank policy announcements, public documents from the State Administration of Foreign Exchange (SAFE), market commentary from mainstream financial media, macroeconomic research reports from securities firms, and retrospective academic analysis reports. It identifies key junctures in the accumulation of vulnerabilities at each stage, the evolution of market expectations, and the merits and demerits of the central bank's intervention measures, thereby elucidating the micro-level transmission mechanism of "institutional constraints - external shocks - market reaction - intervention behaviour - evolution of vulnerabilities".

At the cross-country comparative level, emerging market economies employing similar managed floating exchange rate regimes were selected as a control sample. Drawing on the IMF's *Annual Report on Exchange Rate Arrangements and Exchange Controls (AREAER)* [24],monthly secondary data on central banks' foreign exchange interventions, reserves and cross-border capital flows, we compare differences in intervention tools, intervention frequency and capital management rules across countries. We summarise the successful experiences and lessons learnt from

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various nations' responses to exchange rate depreciation and capital outflows, thereby providing an international benchmark for refining China's managed floating exchange rate framework.

3.6.1 Tracking the Development of a Typical Case: The 2023–2024 Cycle of Foreign Exchange Settlement and Sale Deficits

To address the limitation of purely econometric models-which can only reveal average effects between variables but struggle to illustrate micro-level transmission mechanisms-this paper selects the 2023–2024 stress cycle, during which the foreign exchange settlement and sale balance shifted from a surplus to a substantial deficit, to conduct a process-tracking case study. There are three reasons for selecting this event: 1) This period fully encompasses the transmission chain of 'external shock → market reaction → intervention → escalation of vulnerability'; 2) The foreign exchange settlement and sale deficit was the key trigger for the 2024 vulnerability peak identified by the TVP-VAR model; 3) As the event occurred close to the end of the sample period, data availability is high and information sources are abundant.

(1) Background and Timeline of the Event

From the second quarter of 2023 onwards, the Federal Reserve's sustained interest rate hikes pushed the federal funds rate into the 5.25%–5.50% range, whilst the yield spread between Chinese and US 10-year government bonds inverted, widening from –0.6% to over –1.8%. During the same period, China's current account surplus narrowed; coupled with pent-up expectations of RMB depreciation from earlier periods, enterprises' willingness to convert foreign exchange into RMB continued to weaken.In May 2023, the monthly data on foreign exchange settlements and sales conducted by banks on behalf of clients shifted from a surplus to a deficit, with the deficit for that month standing at approximately US$4.2 billion, bringing to an end a six-month streak of surpluses that had begun in November 2022.

The deficit continued to widen thereafter: by September 2023, it had expanded to US$18.7 billion. That month, the central bank announced a 2-percentage-point cut in the foreign exchange reserve requirement ratio for financial institutions (from 6 per cent to 4 per cent)[27], releasing approximately US$16 billion in foreign exchange liquidity with the aim of alleviating US dollar liquidity tightness in the interbank foreign exchange market.This policy proved effective in the short term, with the deficit narrowing briefly to US$8.9 billion in October. However, entering 2024, external factors such as fluctuating expectations regarding Federal Reserve interest rate cuts and rising geopolitical risks led to a renewed strengthening of depreciation expectations. Consequently, the deficit widened to US$27.5 billion in March 2024, exceeded US$40 billion in May, and reached an annual peak of approximately US$52 billion in August (on a monthly basis).For the year as a whole, the cumulative deficit in banks' spot and forward foreign exchange settlements and sales (including options) reached US$197.1 billion, an increase of 244 per cent compared with the US$57.3 billion recorded in 2023.

(2) Market Reactions and the Evolution of Expectations

As the deficit continued to widen, the foreign exchange market exhibited three distinctive characteristics, corroborating the transmission channels revealed by the econometric model.

First, the deviation between the spot exchange rate and the central parity rate continued to widen.In Q3 2023, the onshore RMB spot exchange rate against the US dollar deviated from the central parity rate by an average of approximately 1.2%–1.5% (intraday); by Q2 2024, this deviation had widened further to 1.8%–2.1%, persistently approaching the upper limit of the 2% fluctuation band. This widening deviation indicates that market depreciation pressures remained consistently higher than the levels reflected by the official central parity rate.

Secondly, the offshore–onshore spread (CNH–CNY) turned positive and became more volatile. In the first half of 2023, the average spread was approximately –80 basis points (with the onshore rate below the offshore rate); in the second half, it turned to +120 basis points; and during the period of pressure in 2024, the spread widened further to +200–350 basis points.The offshore renminbi has long been weaker than the onshore currency, reflecting more aggressive pessimistic pricing of the renminbi exchange rate in overseas markets.

Thirdly, implied volatility in foreign exchange options has risen. The implied volatility of one-year USD/CNY options rose from 4.2 per cent at the start of 2023 to 7.8 per cent by mid-2024, with the volatility term structure exhibiting an inverted pattern (the short end higher than the long end), reflecting a significant

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increase in market concerns regarding a sudden depreciation in the short term.

(3) Record of Central Bank Intervention

Faced with a widening deficit in foreign exchange settlements and sales and mounting depreciation pressure, the central bank's interventions have been characterised by "high frequency, diverse tools and a cautious approach". Key intervention measures include:

July 2023: Raised the macroprudential adjustment parameter for cross-border financing (from 1.25 to 1.5), thereby expanding the cross-border financing quotas for domestic enterprises;

September 2023: Reduced the foreign exchange deposit reserve ratio by 2 percentage points (from 6% to 4%);

January 2024: The Central Bank's Monetary Policy Committee, at its regular meeting, explicitly stated the need to "prevent the formation of unilateral, uniform expectations that become self-reinforcing"; this marked the first time such wording had been included in the minutes of a regular meeting;

April 2024: The State Administration of Foreign Exchange (SAFE) announced the investigation and punishment of a number of Chinese banks for irregular conduct in forward foreign exchange sales, sending a policy signal to "curb speculation on depreciation";

June–August 2024: The central parity rate remained consistently stronger than market expectations, with daily adjustments to the counter-cyclical factor remaining within the high range of 300–800 basis points.

These intervention measures all had some short-term effect-with the exchange rate stabilising within one to two weeks of the policy announcements-but the cycle of "depreciation–intervention–further depreciation" was not fundamentally broken.Following the peak in the deficit in August 2024, the Federal Reserve began a cycle of interest rate cuts in September (a reduction of 50 basis points), leading to a marginal easing of external pressures; by October, the foreign exchange settlement and sales deficit had narrowed to approximately US$21 billion, and the pressure on financial stability had eased somewhat.

(4) Micro-level Mechanisms of Vulnerability Evolution: A Comparison with Empirical Findings

This case study fully illustrates the transmission chain proposed in the paper's introduction-'institutional constraints → external shocks → market reactions → intervention → evolution of vulnerability'-and aligns directly with the empirical findings in three key respects.

First, the positive correlation between exchange rate volatility (X1) and vulnerability was significantly amplified during periods of stress.The average daily standard deviation of spot exchange rate volatility in 2024 reached 4.3 per cent (annualised), higher than the 3.1 per cent recorded in 2022. The coefficient for X1 (0.412) during the high-pressure period shown in Table 10 was approximately double that of the stable period (0.212), consistent with the observation of self-reinforcing depreciation expectations in this case study.

Second, the shift from a surplus to a deficit in foreign exchange settlement and sales (deterioration of X6) constituted the core trigger for the sharp rise in vulnerability.In 2024, the weighting of X6 rose from its previous average of 0.17 to over 0.20 (Table A6), indicating that the discriminatory power of this indicator significantly increased during the deficit cycle. The cycle observed in the case study-where enterprises 'delayed foreign exchange settlement → increased pressure to purchase spot foreign exchange → widening deficit → depletion of reserves → further deterioration of expectations'-corresponds precisely to the microfoundations underlying the significantly positive X6 coefficient in the empirical analysis.

Thirdly, the contraction in foreign exchange trading volume (X4) during periods of stress weakened the market's self-buffering capacity.In 2024, the average daily trading volume in the foreign exchange market fell by approximately 9 per cent compared with 2023; this contraction in liquidity meant that any marginal imbalance between supply and demand would be amplified into a larger price shock-which explains the empirical finding in Table 10 that the absolute value of the X4 coefficient during periods of high pressure (–0.501) was significantly greater than during stable periods (–0.315).

Taken together, the empirical evidence from the 2023–2024 cycle of foreign exchange settlement and sale deficits validates, at the micro-transmission level, the core findings of this paper's econometric analysis: in an environment where high-frequency interventions and one-sided expectations mutually reinforce each other, the endogenous accumulation of foreign exchange market vulnerability exhibits

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non-linear acceleration; whilst liquidity contraction and reserve depletion further weaken the system's shock-absorbing capacity.

3.7 Summary of this Chapter

Based on annual foreign exchange panel data from 2021 to 2024, this chapter conducts a progressive empirical analysis using, in sequence, two-way fixed-effects panel regression, an SVAR static shock model and a TVP-VAR time-varying parameter model, thereby comprehensively mapping the patterns of influence of six core foreign exchange indicators on the structural vulnerability of the foreign exchange market: Firstly, the baseline regression results indicate that exchange rate volatility, short-term cross-border capital outflows and an increase in the proportion of short-term external debt significantly exacerbate foreign exchange market vulnerability; whilst foreign exchange market turnover and foreign exchange reserves play a significant role in hedging against risk; Second, robustness tests-conducted by altering the estimation methods for the dependent variables and by regressing the raw indicators-confirm that the core conclusions remain unaffected by the form of variable estimation; Third, the SVAR model clarifies the transmission pathways of concurrent shocks across variables, demonstrating that foreign exchange market liquidity is the most critical channel for hedging foreign exchange risk; Fourthly, the TVP-VAR model captures the stage-specific heterogeneity of shocks; against the backdrop of multiple overlapping risks in 2024, the impact of negative indicator shocks has significantly intensified, leading to a sharp rise in market vulnerability; By synthesising the three types of empirical results-static, dynamic and time-varying-this study provides quantitative empirical support for the subsequent discussion on preventing systemic foreign exchange risks and refining exchange rate and cross-border capital control policies.

4. Conclusion

4.1 Summary and Innovations

Based on macro- and micro-level foreign exchange market data from 2021 to 2024, this paper selects six core indicators and comprehensively employs the entropy method, two-way fixed panel regression, SVAR, TVP-VAR models and case comparison methods to systematically investigate the characteristics, time-varying patterns and transmission mechanisms of structural fragility in China's foreign exchange market, thereby clarifying the logic of risk accumulation under a managed floating exchange rate regime.The paper overcomes the limitations of existing research, achieving multi-dimensional research innovations, resolving core issues in foreign exchange risk analysis and institutional optimisation, and offering policy implications for risk prevention, control and reform tailored to the current state of China's market.

Empirical results indicate that the foreign exchange market vulnerability index, calculated using the entropy method, reveals that total market trading volume serves as the core buffer for hedging foreign exchange risks. In 2024, driven by the combined impact of domestic and international factors-including interest rate hikes by the Federal Reserve, a substantial deficit in foreign exchange settlements and sales, and rising short-term external debt-the foreign exchange market vulnerability index reached a four-year peak, confirming that routine exchange rate intervention continues to accumulate endogenous structural risks.Fixed-panel regression and robustness tests confirm that heightened exchange rate volatility, short-term capital outflows and a rising proportion of short-term external debt significantly increase foreign exchange vulnerability, whilst foreign exchange trading volume and foreign exchange reserves can effectively mitigate market risks; an expansion in the surplus of foreign exchange settlements and sales amplifies external speculative pressure and elevates vulnerability levels. After re-regressing the data using alternative estimation parameters and original indicators, the core conclusions remain robust and reliable.

The results of shock identification using the SVAR model indicate that negative shocks to the exchange rate and cross-border capital flows exhibit persistent lag effects, which have long-term implications for market stability. Among these, foreign exchange turnover explains the largest proportion of fluctuations in the vulnerability index and is the key variable in blocking risk transmission, a finding corroborated by the entropy calculations.The TVP-VAR time-varying analysis indicates that the global financial cycle and domestic macroeconomic fundamentals significantly alter

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the intensity of shocks, and that foreign exchange vulnerability exhibits distinct phasic time-varying characteristics: in 2022, market buffers were ample and the impact of external shocks was relatively weak; in 2024, domestic and external risks converged, leading to a non-linear amplification of negative shocks and a sharp rise in vulnerability.Through tracking three key periods-the '8·11' exchange rate reform of 2015, the COVID-19 pandemic of 2020, and the exchange rate pressures of 2023–2024-and by comparing these with emerging markets and the ERM II mechanism, it is evident thathigh-frequency direct intervention and the self-reinforcement of one-sided market expectations constitute the core pathways through which risks accumulate; moderately widening the intervention band and enhancing policy transparency can effectively reduce market vulnerability and alleviate pressure from capital outflows.

This paper introduces innovations in three aspects: research perspective, quantitative methods and empirical framework. In terms of perspective, whilst existing literature largely focuses on the shock-resilience of exchange rate regimes, this paper takes a counter-intuitive approach by focusing on systemic risks arising from exchange rate intervention inertia, currency mismatches and one-sided expectations. It constructs a dual analytical framework of 'institutional resilience–endogenous vulnerability', thereby addressing the limitations of existing research that adopts a solely forward-looking perspective.Methodologically, this paper eschews subjective weighting methods such as the Analytic Hierarchy Process (AHP) and expert scoring. Instead, it employs the entropy method to assign weights objectively based on the degree of dispersion of indicators, precisely capturing the fluctuating characteristics of vulnerability, avoiding biases arising from manual weighting, and achieving a dynamic and accurate quantification of foreign exchange vulnerability for the period 2021–2024.Empirically, this paper establishes a progressive econometric system comprising 'static panels-SVAR contemporaneous shocks-TVP-VAR time-varying effects', which isolates macroeconomic confounding factors. By combining tracking of typical events with international comparisons, it overcomes the limitation of pure econometric models-which can only reflect average associations-and comprehensively maps out the micro-level transmission chain of vulnerability formation, accumulation and evolution.

Building on the aforementioned research framework and empirical findings, this paper effectively addresses four core research questions. Firstly, it constructs a framework for analysing foreign exchange vulnerability tailored to China's national conditions, integrating dimensions such as exchange rate volatility, capital flows, currency mismatches, market liquidity and policy buffers, whilst incorporating both endogenous and exogenous shock variables, thereby clarifying the nature, sources and transmission channels of vulnerability.Second, by optimising the modelling frequency through monthly interpolation of annual indices, the study accurately identifies the temporal heterogeneity of foreign exchange vulnerability and effectively captures the phased differences in market risk between 2021 and 2024.Third, the study clarifies the risk prevention and control logic underlying the expansion of exchange rate flexibility, confirming that routine high-frequency intervention accumulates structural risks, whilst widening the exchange rate floating band and enhancing trading liquidity can build endogenous risk buffers, thereby providing a supporting risk management framework for exchange rate marketisation reforms.Fourthly, drawing on the experience of ERM II and interventions in emerging markets, the study verifies the risk management value of moderate intervention, high policy transparency and policy coordination; combining these with the characteristics of the domestic market, it proposes a long-term pathway for optimising the exchange rate regime and the internationalisation of the renminbi.

Based on the research findings, this paper proposes five targeted policy implications. Firstly, expand the range of market participants and tradable instruments in the foreign exchange market to enhance market liquidity, consolidate the foundation for risk buffers, and reduce structural vulnerabilities at source. Secondly, optimise the central bank's intervention model by reducing routine, high-frequency interventions, enhancing policy transparency, guiding the market to form two-way equilibrium expectations regarding the exchange rate, and curbing the accumulation of one-sided risks.Thirdly, coordinate the management of short-term capital flows with the optimisation of

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medium- to long-term external debt structures, reduce the scale of currency mismatches, and mitigate the risk transmission effects of external interest rate hike cycles.Fourthly, a global cycle early-warning system comprising indicators such as the VIX, the US Dollar Index and the China–US interest rate spread should be established to monitor and hedge against external risks on a routine basis. Fifthly, drawing on mature international governance practices, a multi-sectoral policy coordination and regulation mechanism should be established to steadily expand exchange rate flexibility whilst adhering to the managed floating exchange rate system, and to balance market-oriented reforms with the prevention and control of systemic risks, thereby ensuring the smooth progress of the renminbi's internationalisation[25].

4.2 Research Limitations and Future Directions

Whilst this paper has undertaken a systematic exploration of theoretical frameworks, quantitative methods and empirical strategies, several limitations remain that require addressing in future research.

Firstly, data availability constrains the sample period. The sample period for this paper spans 2021–2024, comprising a total of four annual observations. Although linear interpolation was used to extend the data to monthly frequency to meet the requirements of SVAR/TVP-VAR modelling, the information content of the interpolated series is limited and cannot be equated with genuine high-frequency observational data; consequently, the estimation accuracy falls short of that achieved in large-sample studies.Future research, once data conditions improve (such as through access to longer-span monthly balance of payments and foreign exchange settlement and sale data), could extend the sample to cover the full cycle since the second exchange rate reform in 2010, or characterise risk transmission patterns at a finer daily frequency.

Secondly, the measurement of foreign exchange intervention requires further refinement. This paper uses 'foreign exchange reserves' and the 'net foreign exchange settlement and sale balance' to indirectly reflect the central bank's intervention behaviour, rather than directly utilising official announcements of intervention events or transaction data.In recent years, central banks have increasingly adopted non-reserve-based intervention tools such as 'counter-cyclical factors', 'adjustments to cross-border financing parameters' and 'window guidance'; the effects of these measures are difficult to capture fully through changes in reserves. Future research could manually collate public announcements-such as central bank monetary policy implementation reports and the State Administration of Foreign Exchange's responses to press enquiries-to construct a database of direct intervention events, thereby enabling the precise identification of intervention effects.

Thirdly, the depth of cross-country comparison is limited. This paper merely conducts a directional comparison between the ERM II mechanism and intervention practices in emerging markets, without introducing a quantitative comparative framework for specific countries. Future research could select three to five emerging economies operating under a managed floating exchange rate regime (such as India, South Korea and Thailand), construct a unified system of foreign exchange market vulnerability indicators, and conduct cross-country panel regression or synthetic control method analyses to extract transferable policy insights.

Fourthly, there is a lack of data on micro-level agent behaviour. The analysis in this paper focuses on the macro-market level and fails to directly examine the micro-level interactions between firms' exchange rate hedging behaviour, banks' foreign exchange settlement and sale decisions, and exchange rate expectations. Future research could utilise questionnaire surveys or firm-level cross-border receipts and payments data to test the micro-level channel of 'expectation rigidity → changes in foreign exchange settlement and sale behaviour → accumulation of vulnerability', thereby strengthening the micro-level foundation of the theoretical assumptions.

Acknowledging these limitations does not diminish the reference value of this paper's core conclusions; rather, it points to avenues for further research. Against the backdrop of continuously evolving data environments and econometric methods, the topic of structural vulnerability in foreign exchange markets still offers vast scope for research.

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