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Exchange Rates, Trade Openness and Inflation: Empirical Evidence from a(N)ARDL Model

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ABSTRACT

This study investigated the linear and nonlinear effects of trade openness and the real effective exchange rate on inflation in China from 2003 to 2023. It examined the influence of external trade on inflation under rising global inflation and U.S.-China trade tensions. Four macroeconomic variables gross domestic product, money supply, crude oil prices, and interest rates were included as controls. Linear and nonlinear autoregressive distributed lag models were applied to explore short- and long-term impacts. The findings indicated a negative long-term relationship between trade openness and inflation. In the short term, the real effective exchange rate was negatively related to inflation. Nonlinear analysis revealed asymmetric inflation responses to trade openness, suggesting the importance of considering nonlinear dynamics in inflation modeling.

KEYWORDS: Chinese economy, monetary policy, nonlinear autoregressive distributed lag model, asymmetric effects, external economic shocks

1. Introduction

Prior to the early 1990s, China had been practicing a fixed exchange rate system, in which the exchange rate between the RMB and the U.S. dollar remained essentially unchanged. At the beginning of the twenty-first century, China implemented a reform of its exchange rate system, which meant that the exchange rate between the RMB and the US dollar was no longer completely fixed but was instead adjusted on a floating basis concerning a basket of currencies. The IMF classifies China's exchange rate regime as a de jure managed floating regime and a de facto other managed regime (IMF, 2024). This has made the RMB's exchange rate more reflective of market supply and demand and economic fundamentals. As China has deepened its international trade and opened up more to the outside world, the imported nature of its inflation has become increasingly evident. In recent years, an increase in international commodity prices, represented in this paper by international crude oil, has been transmitted to China's inflation through international trade channels with the help of the RMB exchange rate. China's economy has become more sensitive to external market movements through increased sensitivity in the global supply chain, and this trend has placed higher demands on financial and economic strategies, requiring more flexible and adaptive responses.

In this study, we employ ARDL and NARDL models to assess the long-run asymmetric impacts of both positive and negative shocks on inflation. The asymmetric dynamic adjustment of inflation is portrayed using the dynamic multipliers, which analyse the transmission effects of the determinants affecting inflation in China. Compared to previous studies, we use a longer span of quarterly data from 2003 to 2023, covering the period in which the economy responded to the aftermath of the COVID-19 crisis. The empirical result shows that trade openness and real exchange rates have a long-run asymmetric effect on inflation. The asymmetric effect of determinants on inflation seems to be driven by periods of global crises. In addition, we find positive effects of oil prices and GDP on inflation but negative effects of M2 on inflation, which seems to be driven by the specifics of the Chinese economy.

Examining both the short- and long-term effects of inflation drivers in China is crucial for understanding their impact on the domestic price level. Additionally, comparing the asymmetric effects of positive and negative shocks on inflation can provide insights into stabilizing prices and fostering economic growth. Our findings offer a deeper understanding of these dynamics and may inform the development of more effective policy measures.

The structure of the paper is as follows: Section 2 provides a concise review of the relevant literature. Section 3 outlines the data and empirical methodology used in the analysis. Section 4 presents a discussion of the empirical results, followed by the conclusion in the final section.

2. Literature Review

The impact of exchange rate changes on prices in China was investigated using a structural vector autoregression (SVAR) model, with findings indicating that exchange rate pass-through to the producer price index (PPI) and retail price index (RPI) is generally incomplete, and the pass-through to the PPI is higher and faster than to the RPI (Jiang and Kim, 2013). Zhu and Liu (2012) employed the ARDL model on data from 1980 to 2010 and found a positive correlation between the RMB exchange rate and inflation. Liu and Chen (2017) claimed that RMB appreciation may lead to a decline in inflation, and that exchange rate pass-through to domestic inflation was limited but is growing since the 2005 reform of the foreign exchange rate system. In summary, China's inflation problem cannot be explained solely by "domestic economic imbalances". Previous research has shown that inflation in China is primarily influenced by factors such as excess liquidity, the output gap, and asset prices (Huang

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et al, 2010). While the exchange rate and real interest rates have a weaker influence, the role of liquidity and the output gap in shaping inflation trends cannot be overlooked. Bei and Zhu (2008) concluded that there is no direct relationship between exchange rates and inflation in China. Overall, the results of the existing studies are mixed and require further analysis.

Recent studies indicate that trade openness in developing countries can help lower domestic inflation, with the effect of export openness outperforming imports in reducing inflationary pressures (Chhabra, Giri, and Kumar, 2024). Zhuang et al. (2021) identified a negative relationship between inflation and trade openness, suggesting that higher inflation tends to hinder trade openness. However, they also highlighted that institutional quality plays an important moderating role in this relationship, helping to buffer the negative effects of inflation on trade openness. Kaukab and Anggara (2024) examined the relationship between trade openness and inflation in Indonesia and found that, in the long run, trade openness is positively correlated with inflation. This suggests that greater trade openness may contribute to higher inflationary pressures. The study also highlights the importance of other factors, such as real GDP and foreign direct investment (FDI), which are found to negatively influence inflation, thereby reducing its overall impact. Using the ARDL model, Tahir et al. (2023) find that China's trade openness during the period 1987-2019 had a negative impact on inflation. Also, exchange rate and money supply positively affected inflation.

In terms of the empirical approach, linear models have been widely used in previous studies. However, there can be significant non-linearities in the effects of inflation determinants, which are influenced by economic activity, such as possible downward price rigidity. Therefore, some recent papers have adopted non-linear models to study the effects of inflation drivers. Kayamo (2021) conducted a study on the asymmetric effects of the real exchange rate on inflation in Ethiopia, covering the period from 1982 to 2019. The study concluded that the real exchange rate exerts an asymmetric influence on inflation, both in the short term and the long term. Meng et al. (2014) explored the nonlinear relationships between various macroeconomic variables and inflation, finding that several factors affect inflation in a nonlinear manner.

Zhao and Ding (2012) employed the smoothed transformed regression (STR) model to examine the potential nonlinear relationship between trade openness and inflation, while also accounting for the impact of fluctuations in the RMB exchange rate and international oil prices. Their findings reveal a significant nonlinear association between trade openness and inflation in China, highlighting the complex nature of this relationship.

3. Methodology and Data

In this study, we use the NARDL model, which is a derivative of the ARDL model. The basic specification of the ARDL model is as follows:

$$y_t = \alpha + \sum_{i=0}^{p} \emptyset_i y_{t-i} + \sum_{i=0}^{q} \beta_i x_{t-i} + u_t \qquad (1)$$

where y_t represents the dependent variable, which is explained by the constant α, lagged values of y_t, explanatory variables x_t, and an error term u_t. The indices p and q indicate the optimal number of empirically determined lags for dependent and explanatory variables, respectively. The model includes a "distributed lag" component, where the current value of $x_t$may be excluded from the lagged explanatory variables in some specifications. With long- and short-term asymmetries in mind, Shin et al. (2014) develop a very flexible dynamic parametric framework capable of incorporating both long- and short-term asymmetries, in which the traditional linear error correction model (ECM) is extended to a more general covariance of the NARDL model. The fundamental specification of the NARDL model is presented below:

$$\Delta y_t = \alpha + \rho y_{t-i} + \theta^+ x_{1,t-1}^+ + \theta^- x_{1,t-1}^- + \cdots + \beta^+ x_{n,t-1}^+ + \beta^- x_{n,t-1}^- + \sum_{i=1}^{p-1} \varphi_i \Delta y_{t-i} + \sum_{i=0}^{q} \pi^+ \Delta x_{1,t-i}^+ + \sum_{i=0}^{q} \pi^- \Delta x_{1,t-i}^- + \cdots + \sum_{i=0}^{q} \lambda^+ \Delta x_{n,t-i}^+ + \sum_{i=0}^{q} \lambda^- \Delta x_{n,t-i}^- + u_t \qquad (2)$$

NARDL is an asymmetric effects model for the long and short term. θ... β are long-term coefficients, π... λ are short-term coefficients; and the NARDL model is divided into positive and negative fluctuations. Equations 3 and 4 describe the cumulative sum of positive and negative changes, respectively.

$$[X(X_1, \ldots, X_N)]^+ = \sum_{j=1}^{t} \Delta X_j^+ = \sum_{j=1}^{t} \max(\Delta X_j, 0) \qquad (3)$$

$$[X(X_1, \ldots, X_N)]^- = \sum_{j=1}^{t} \Delta X_j^- = \sum_{j=1}^{t} \min(\Delta X_j, 0) \qquad (4)$$

The application of the NARDL model for empirical analysis consists of the following steps.

First, we estimate the equations using the standard OLS approach, which sets up the model without constraints. Second, we test for the existence of an asymmetric long-run equilibrium relationship between the variables Δy_t, x_t^+, and x_t^-. Third, we test for long-run and short-run asymmetries using the standard Wald test. Fourth, if asymmetry exists, we calculate the positive and negative asymmetric dynamic multipliers to represent the cumulative dynamic multiplier effects of unit changes in x_t^+, and x_t^- , respectively, on Δy_t. Before drawing conclusions, it is important to ensure that our NARDL model errors are serially independent, normally distributed, and homoscedastic. Therefore, we perform relative post-estimation diagnostic tests including normality test, linearity test and stability test.

In this study we explain the inflation rate using its lagged values and the vector of five macroeconomic variables. The inflation rate is represented by the consumer price index (CPI) rate. The Real Effective Exchange Rate (REER) index, sourced from the Bank for International Settlements (BIS), is calculated as weighted averages of bilateral exchange rates adjusted for relative consumer prices, using 2005 as the base year (BIS, n.d.). Trade openness (OPEN), calculated as the ratio of total trade in goods and services to nominal GDP, is a widely used measure to assess the extent of a country's integration into the global economy. In addition, we incorporate key macroeconomic factors that may influence inflation to ensure our ARDL model is comprehensive. Interest rate (IR) defined as the one-year benchmark lending rate. Crude oil price (OIL) and money supply (M2) are averaged from monthly data from the World Bank. To

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avoid pseudo regression and eliminate heteroscedasticity, the natural logarithm of the time series is usually taken without changing the nature of the time series and correlation to obtain smooth data. We performed a logarithmic transformation on all data except IR.

4. Results and Discussion

4.1. Results of Unit Root and linear ARDL Cointegration Tests

First, we discuss the results of the linear regression model. The ARDL model gives us the flexibility to use variables of different orders of integration – I(0) and I(1) – in a single equation. However, ARDL should not be used in the case of integration of order I(2). According to unit root tests presented in Table 1, all variables are either I(0) or I(1), which is consistent with the model assumption. Based on the Akaike Information Criterion (AIC), the optimal lag structure of the inflation equation is ARDL (4, 2, 0, 0, 3, 1, 4).

Table 1. Unit root test results: Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests.

	ADF		PP	
Variables	Level	1st diff	Level	1st diff
LNCPI	0.402	0.000	0.068	0.000
LNGDP	0.989	0.000	0.000	0.000
LNM2	0.989	0.034	1.000	0.000
LNOIL	0.602	0.000	0.520	0.000
LNOPEN	0.150	0.013	0.355	0.000
LNREER	0.718	0.000	0.855	0.000
IR	0.120	0.000	0.334	0.000

Note: The values reported for both ADF and PP tests are the one-sided p-values (MacKinnon, 1996).
Source: Research findings

For most variables (e.g., LNCPI, LNGDP, LNM2, LNOIL, LNOPEN, LNREER, and IR), the p-values at levels exceed standard significance thresholds (e.g., 0.05 or 0.01), suggesting the presence of a unit root. These variables are non-stationary in their original form. At first differences, the p-values for all variables fall below 0.05, indicating stationarity. This confirms that the variables are integrated of order I(1), which is a necessary condition for employing the ARDL framework. The results of ADF and PP tests are largely consistent, with slight variations for specific variables. The mixed integration order (I(0) and I(1)) observed in the variables justifies the use of the ARDL model, as it is suitable for variables of this nature, provided no variable is I(2).

Table 2. Bounds test for ARDL Cointegration result

F-Statistics	Critical Value at 1 % sig. level	
	I(0)	I(1)
7.514***	3.219	4.526

Notes: *** denotes rejection of the null hypothesis at 1 % significance level.
Source: Research finding

Table 2 presents the results of the bounds test for cointegration using the ARDL framework. The calculated F-statistic value of 7.514 significantly exceeds the upper critical bound value of 4.526 at the 1% significance level. This outcome leads to the rejection of the null hypothesis, which posits the absence of a level relationship among the variables. Consequently, the presence of a long-run equilibrium relationship between inflation and the explanatory variables is confirmed. With evidence of cointegration established, the estimation of a long-run model becomes appropriate (Pesaran et al., 2001; Narayan, 2005).

Table 3. Long-run estimates and results of the ARDL Model

Variable	Coefficient	t-Statistic	Prob
LNCPI(-1)	0.770*	6.745	0.000
LNCPI(-2)	0.105	0.667	0.507
LNCPI(-3)	-0.033	-0.220	0.827
LNCPI(-4)	-0.358***	-3.250	0.002
LNGDP	0.004	0.268	0.790
LNGDP(-1)	0.039**	2.265	0.027
LNGDP(-2)	0.042**	2.099	0.040
LNM2	-0.063**	-2.174	0.034
IR	-0.001	-0.378	0.707
LNOPEN	0.006	0.252	0.802
LNOPEN(-1)	0.040	1.566	0.123
LNOPEN(-2)	0.006	0.229	0.820

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LNOPEN(-3)	-0.044***	-1.875	0.066
LNREER	0.049	1.140	0.259
LNREER(-1)	-0.089***	-1.840	0.071
LNOIL	0.021*	3.446	0.001
LNOIL(-1)	-0.018***	-1.835	0.072
LNOIL(-2)	-0.027**	-2.668	0.010
LNOIL(-3)	0.006	0.706	0.483
LNOIL(-4)	0.017**	2.507	0.015
Constant	2.510*	6.735	0.000
R^2	0.925	Adjusted R^2	0.899

Notes: *, ** and *** show significant values at 1%, 5% and 10%, respectively. The "Akaike Information Criterion (AIC)" has been used to determine the optimum lag length of the model.
Source: Research findings

The long-run coefficients derived from the ARDL model provide critical insights into the inflation dynamics in China. A statistically significant and positive relationship between GDP and inflation is observed, but only at the first and second lags. This implies that economic growth, as measured by GDP, exerts a lagged stimulative effect on inflation. This aligns with the demand-pull inflation theory, where increased economic activity elevates aggregate demand, subsequently driving prices upward (Mankiw, 2012). Interestingly, contrary to conventional economic theory, the broad money supply M2 exhibits a negative relationship with inflation. This finding supports the argument that a reduced velocity of money circulation dampens the inflationary effects of monetary expansion. According to the People's Bank of China's 2023 Monetary Policy Report, this decoupling reflects the lagged impact of monetary policy measures and constrained household consumption amidst elevated savings rates. The REER also reveals a nuanced effect, showing a negative correlation with inflation after the first lag. This finding is consistent with the theory that currency appreciation reduces import prices and curbs inflationary pressures (Ha, Stocker, & Yilmazkuday, 2020). Crude oil prices exhibit a mixed impact on inflation. The coefficients fluctuate between positive and negative values across different lags. Initially, oil price shocks stimulate inflation, reflecting immediate cost-push effects. However, the observed negative effects at the second lag and a reversion to positive at the fourth lag suggest complex dynamics, possibly linked to adjustments in energy subsidies or global demand shifts. Regarding trade openness, a significant negative relationship emerges at the third lag, corroborating earlier studies such as Romer (1993), and more recent findings by Tahir et al. (2023). This suggests that higher openness tends to suppress inflation, potentially due to increased competitive pressures and efficiency gains in production. While the magnitude of this effect is relatively small, it reinforces the view that trade liberalization contributes to price stability.

4.2. Results of Non-linear ARDL Cointegration and Symmetry Tests

In the following model, we examine the potential asymmetric effects of trade openness and REER on inflation in China, treating these two variables as nonlinear factors over the long run while maintaining linear assumptions for the remaining variables.

Table 4. Long-run estimates and results of NARDL model

Variable	Coefficient	t-Statistic	Prob
LNCPI(-1)	-0.630	-6.841	0.000
LNGDP(-1)	0.219	4.469	0.000
LNM2	-0.233	-3.873	0.000
LNOIL(-1)	-0.018	-2.920	0.005
IR	-0.002	-1.107	0.273
@CUMDP(LNREER)	-0.101***	-1.958	0.055
@CUMDN(LNREER)	0.097**	2.206	0.031
@CUMDP(LNOPEN(-1))	0.091*	3.868	0.000
@CUMDN(LNOPEN(-1))	-0.047***	-1.909	0.061
Constant	3.470	7.272	0.000
D(LNCPI(-1))	0.346	3.464	0.001
D(LNCPI(-2))	0.375	3.794	0.000
D(LNCPI(-3))	0.315	3.062	0.003
D(LNGDP)	0.048	2.694	0.009
D(LNGDP(-1))	-0.103	-3.888	0.000
D(LNGDP(-2))	-0.047	-3.102	0.003
D(LNOIL)	0.006	0.830	0.410
D(LNOIL(-1))	0.020	2.998	0.004
D(LNOPEN)	0.009	0.414	0.680
R^2	0.724	Adjusted R^2	0.640

Notes: *, ** and *** show significant values at 1%, 5% and 10%, respectively. The "Akaike Information Criterion (AIC)" has been used to determine the optimum lag length of the model.
Source: Research finding

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The NARDL model's results indicate a nuanced, asymmetric relationship between trade openness and inflation in China over the long term. Increases in trade openness exhibit an inflationary effect, aligning with the compensation hypothesis, which posits that adjustments to globalization can spur cost-push inflation as economies adapt to new competitive pressures (Ghosh, 2014). Conversely, reductions in trade openness correlate with deflationary pressures, but their impact is smaller in magnitude and statistically significant only at the 10% level. This asymmetry is validated by the Wald test (Table 5), which confirms that the effects of trade openness on inflation differ significantly depending on the direction of the change.

Table 5. Symmetry test

Variable	Statistic	Value	Prob
LNOPEN	F-statistic	10.604	0.002
	Chi-square	10.604	0.001
LNREER	F-statistic	5.635	0.021
	Chi-square	5.635	0.018

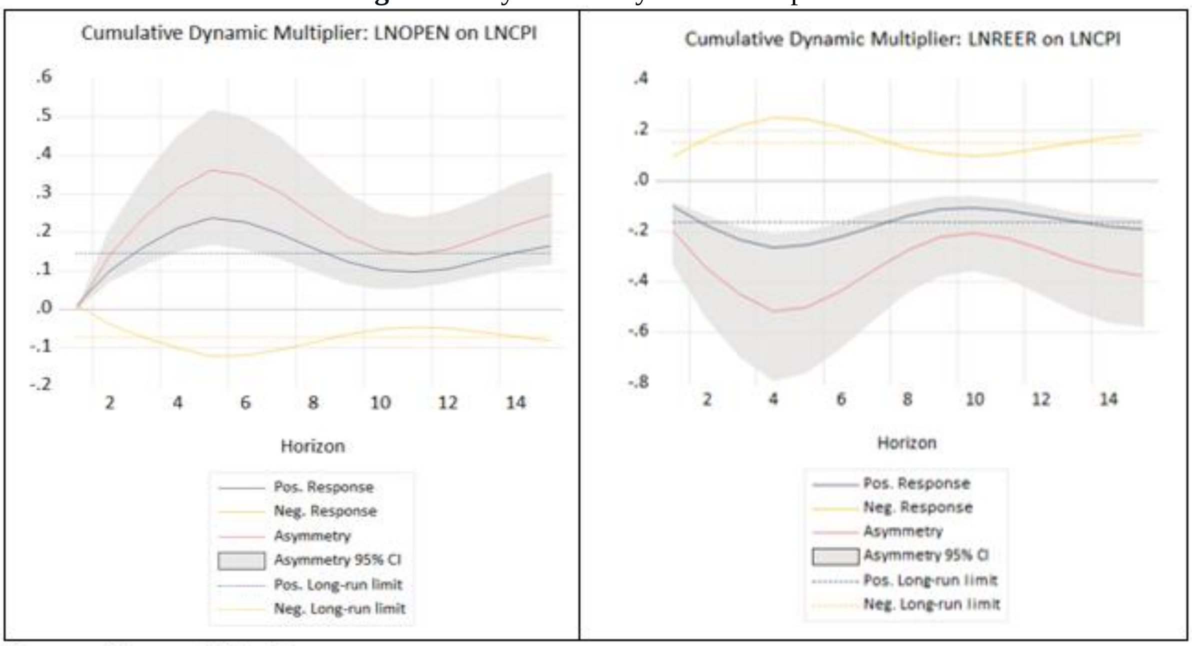
Source: Research finding

Regarding the effect of the REER on inflation, the estimated asymmetry (LR) test rejects the null hypothesis, which provides statistical evidence that REER has an asymmetric effect on inflation in the long run. In the long run, every unit increase in REER decreases inflation by 0.101%. The appreciation of RMB relative to a basket of currencies makes imports cheaper and may reduce inflation. Conversely, every unit decrease in REER increases the inflation by 0.097%. Overall, inflation is more responsive to an increase in REER than to its decrease, but the opposite is true for their significance. The asymmetric impact of REER on inflation may be driven by differences in monetary policy responses by central banks. In response to an appreciating currency, central banks may be proactive in implementing accommodative monetary policies to counter deflationary pressures. However, in the case of a depreciating currency, central banks may act more swiftly to tighten monetary policy to control inflation and stabilize the currency. Price stickiness can be another reason. Prices in many markets may be sticky, meaning they do not adjust immediately to changes in costs. If the REER rises and imports become cheaper, it may take some time for companies to adjust their prices downward as they seize the opportunity for temporarily higher profits. On the other hand, if the REER falls and import prices increase, firms may be flexible in passing on these cost increases to consumers, contributing to a more immediate impact on inflation. To further analyze the dynamics of inflation responses to positive and negative shocks, we proceed with the dynamic multiplier approach.

4.3. Asymmetric dynamic multiplier

The asymmetric cumulative dynamic multiplier diagram shows the pattern of adjustment of inflation towards its new long-run equilibrium following a positive or a negative shock to trade openness and REER. The asymmetric curve illustrates the linear combination of dynamic multipliers for both positive and negative shocks, displayed alongside 95% confidence intervals. The solid black line illustrates how inflation adjusts over time following a positive shock to the explanatory variable, while the dashed black line represents the adjustment path after a negative shock. Figure 1 highlights the asymmetry in these responses by plotting the divergence between the dynamic multipliers for positive and negative changes in the independent variable.

Figure 1. Asymmetric dynamic multiplier



Source: Research finding

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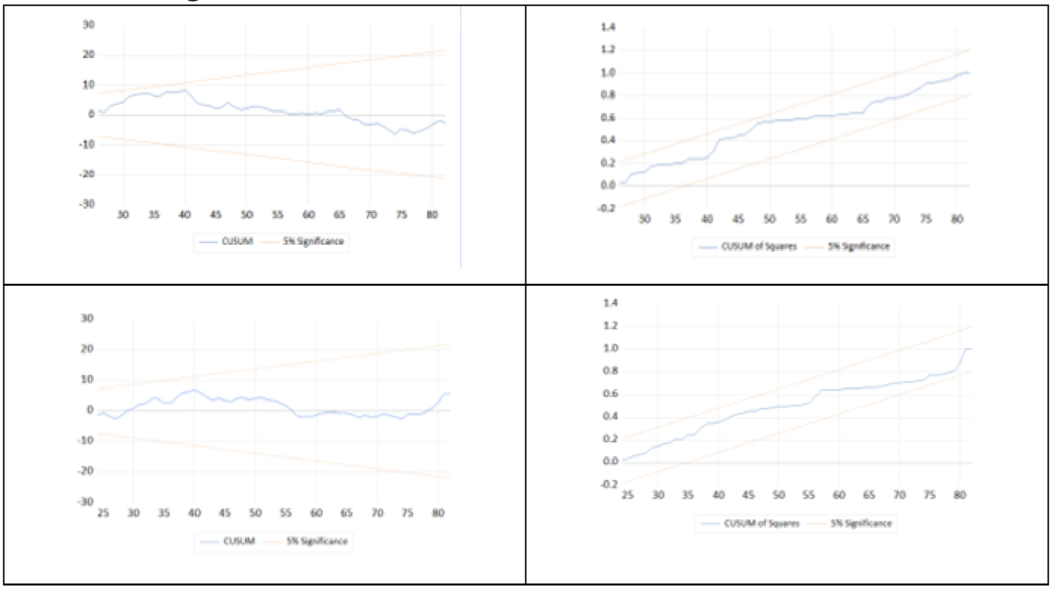
4.4. Stability test

To verify the model's stability, the study applies the CUSUM and CUSUM of Squares tests, as introduced by Brown, Durbin, and Evans (1975). These tests examine whether the cumulative sums of recursive residuals and their squares remain within predefined boundaries over time. Stability is confirmed if the plotted statistics stay within the critical bounds at a 5% significance level, indicating that the model's parameters are consistent and free from structural shifts throughout the evaluation period.

Figure 2. Plots of CUSUM and CUSUMSQ in NARDL model



Source: Research finding

Given that the test statistics (represented by the blue lines) do not exceed the critical values for either test, as shown in Figure 2, we fail to reject the null hypothesis of coefficient stability with constant volatility at the 5% significance level. Consequently, the results suggest that the coefficients of the NARDL model remain stable over the period from 2003Q1 to 2023Q2.

5. Conclusion

In this paper, we provide new evidence on the linear and nonlinear effects of trade openness and real effective exchange rate on inflation in China. Using the NARDL model for quarterly time series data from 2003 to 2023, the linear and asymmetric effects of macro variables on inflation in China are captured through the cointegration test and dynamic multipliers. Long-term asymmetries are analyzed by decomposing the sum of the positive and negative components of trade openness and REER while controlling for the effects of GDP, M2, crude oil prices, and interest rates. The main findings of this study are as follows.

In the linear model, REER and inflation are negatively correlated at the first lag, suggesting that currency appreciation may dampen inflation. Non-linear specification of REER effects on inflation reveals asymmetric responses of inflation to positive and negative REER shocks. In the long run, when the RMB exchange rate rises, inflation falls. When the RMB exchange rate rises, it means that the RMB appreciates relative to a basket of other currencies. This can reduce the price of imports, which is then reflected directly or indirectly in the prices of final products, thereby reducing inflation. In addition, a fall in the RMB exchange rate can lead to a rise in the inflation rate. Overall, inflation responds more to a rise in the real exchange rate than to a fall in the real exchange rate. The reasons for the non-linear relationship between REER and inflation may be due to central bank policy responses, price stickiness, lagged effects, and international supply chain influences.

In a linear framework, there is a negative long-run correlation between trade openness and inflation. The response of inflation to trade openness in the nonlinear framework is asymmetric in the long run. The estimates show that an increase in trade openness is inflationary in the long run, and a decrease in trade openness has a smaller effect on inflation than an increase in trade openness.

Overall, our findings suggest that the relationship between trade openness and inflation is more complex and nonlinear than often assumed. Simple models that assume a straightforward, linear link may not fully account for the different ways trade openness can influence inflation. Policymakers should be aware that, under certain conditions, expanding trade openness could lead to higher inflation, possibly due to increased competition, shifts in industry structure, or external price shocks. On the other hand, reducing trade openness doesn't always result in the expected decrease in inflation.

The nonlinear model also offers a more accurate representation of the varied effects of REER changes on inflation. For instance, currency appreciation tends to have a stronger deflationary impact, whereas depreciation may lead to a more immediate and pronounced inflationary effect. Policymakers should adopt flexible monetary policies to address the asymmetric effects of REER changes on inflation. During currency appreciation, supportive measures such as easing interest rates can stimulate growth, while depreciation requires swift tightening to control

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inflation. Additionally, strengthening domestic supply chains and reducing import dependency can enhance economic resilience to external shocks.

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