Asymmetric Causal Relationship between Stock Price and Exchange Rate in Taiwan - Threshold ECM Analysis

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Abstract

Employing the threshold error-correction model, we investigate the asymmetric causal relationship between stock price and exchange rate in Taiwan using both the daily closing data running from 1994 to 2004. The results from Granger-Causality tests based on corresponding threshold error-correction model (TECM) clearly point out a bidirectional feedback causality relationship between stock and exchange rate markets both in the short-run and in the long-run and for both regions above and below the threshold level. Furthermore, we find asymmetric price transmissions between these two markets in the long run that adjustments towards the long-run equilibrium relationship between stock price and exchange rate are faster when the previous disequilibrium level between these two assets is low than when it are high. However, the phenomenon is significant only in the stock market. These findings ought to be made readily available to individual investors and financial institutions holding long-term investment portfolios in these two asset markets for their likely implications.

Key Words: Threshold Error-Correction Model, Asymmetric Causality, Stock Markets, Exchange Rate
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I. Introduction

The relationships between stock price and exchange rate have been heavily examined and analysed by academics and practitioners within the past three decades since the commencement of the floating exchange rate regime in 1973. The lead-lag short-run dynamic and long-run equilibrium relationships between these two financial assets can be utilized as a foresight instrument for investors and speculators for possible arbitrages.

As argued in the theory of "Uncovered Interest Rate Parity"(UIRP), the expectations of relative currency values influence the levels of domestic and foreign interest rates, which in turn affect the present value of a firm's assets. This suggests that exchange rates play a considerable role in determining the trend of stock prices.[1] The "stock-oriented" models of exchange rates by Branson (1983) explain that exchange rates are viewed as serving to equate the supply and demand for assets such as stocks and bonds. Moreover, the interactions between exchange rate and stock price are theoretically argued that a growing economic draws the stock market into an up-trend movement and, at the same while, causes the domestic currency to appreciate, especially for an export-led country. Exchange rate and stock price are thus negatively related.[2] However, for those of imported-oriented firms, the stock price should be positively related to the movement of exchange rate owing to the cost variation. For instance, depreciation implies an increasing in the foreign price and thus cause a higher import cost. Studies have also examined firms’ exchange rate "exposure." As Adler and Dumas (1984) point out, the concept of exposure is arbitrary in the sense

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[1] The stock prices describe the present values discounted from future cash flows of their firms

[2] The exchange rates are under American quotation, i.e., the amount of New Taiwan dollars (NTD) for a unit of US dollar. Therefore, an appreciation of NTD implies negative sign of exchange rate movement

that stock prices and exchange rates are determined jointly.[3] By assuming that capital markets react fully and instantaneously to changes in a country's currency, studies have encountered limited success in identifying a significant correlation between stock prices and a currency's fluctuations. (See: e.g., Bodnar and Gentry (1993), Barton and Bodnar (1994) and Choi (1995).)

The empirical analysis for the relationships between stock prices and exchange rates can be found in numerous literature, but the results are somewhat mixed as to the significance and the direction of influences between stock prices and exchange rates. Aggarwel (1981) and Ayarslan (1982) by traditional statistical methods and Dropsy and Nazarian-Ibrahimi (1994), Ajayi and Mougoue (1996), Kim (2002) and Mishra (2004) among others by newly developed time-series methodologies all find significant interactions between these two financial variables. The studies of Bahmani-Oskooee and Sohrabian (1992) and Nieh and Lee (2002), on the other hand, suggest no co-movement between stock prices and exchange rates.

To be more specified, the profits of industries with heavy international trade activities are extremely sensitive to the movement of the exchange rate. For instance, export orientated industries lose their competitive power and hence decrease the stock prices once the exchange rate appreciate and, on the other hand, import orientated industries benefit from their cost saving opportunities and increase their stock prices upon the appreciation of the exchange rate. However, different time spans and time frequencies may encount problems of inconsistent outcomes. Besides, various techniques employed for investigating the relationships between these two financial assets have also found different results. The interpretation of these inconsistent results

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[3] Exposure describes the relationship between changes in the value of a country's currency and contemporaneous changes in the value of the firm in question as measured by stock prices.

can be counted down on the wrong form of model specification. Noting on the previous studies, it’s not difficult to find that researchers are mostly focus on linear specified model when examining on the relationships between stock prices and exchange rates. The ignoring of nonlinear phenomenon may bias the true facts in examining the relationships among financial assets. The motivation behind our study is to find a foresight possibility for arbitrage in investing in the two financial markets of stock and exchange rate. Unlike most studies in the literature that only investigate the contemporaneous and linear relationship among time series, this paper employ the newly threshold error-correction model elaborated by Enders and Granger (1998) and explained by Enders and Siklos (2001) (EG-ES hereafter) to investigate price transmissions between the stock and exchange rate markets in Taiwan over the 1995 to 2004 period. The results from Granger-Causality tests based on corresponding threshold error-correction model (TECM) clearly point out a bidirectional feedback causality relationship between markets of stock and exchange rate. Asymmetric price transmissions between these two markets are also found in the long run.

The remainder of this study is organized as follows. Section II describes the data source. Section III introduces the methodologies employed and analyzes the empirical findings. We conclude this paper in Section IV.

II. Data

A total of 2945 observations contain daily closing data of stock price (Taiwan weighted stock index, TWSI) and exchange rate (NTD/USD) within ten years running from 1994 to 2004 are both collected from Taiwan Economic Journal (TEJ). An examination of the individual data series makes it clear that logarithmic transformations are required to achieve stationarity in variance; therefore, all the data series are transformed to logarithmic form.

Descriptive statistics for both exchange rates and stock prices are exhibited in Table 1. We find that the sample means of the NTD/USD exchange rate is 30.997 and the TWSI stock price is 6470. The skewness and kurtosis statistics, together with the Jarque-Bera normality test, indicate that the distributions of the series of both markets are non-normal. The Ljung-Box statistics for 4 lags applied to the series and square series show that significant non-linear dependencies exist in both the NTD/USD exchange rate and TWSI stock price. This indicates that the model should be specified as an autoregressive (AR) model.

<Insert Table 1 about Here>

III Methodologies and Empirical Results

A. Unit Root Tests

Recently, there is a growing consensus that exchange rate and stock price might exhibit non-linearities and that a conventional test such as the ADF (Dickey and Fuller, 1981) unit root test has lower power in detecting its mean reverting (stationary) tendency. As such, this study employs a newly developed nonlinear stationary test advanced by Kapetanios et al. (2003) (henceforth, KSS test) to determine whether the stock price and real estate price are nonlinear stationary.

The KSS nonlinear stationary test is based on detecting the presence of non-stationarity against nonlinear but globally stationary exponential smooth transition autoregressive (ESTAR) process:

$$\Delta Y_t = \gamma Y_{t-1}\{1-\exp(-\theta Y_{t-1}^2)\} + \nu_t , \qquad (1)$$

where Y_t is the data series of interest, ν_t is an i.i.d. error with zero mean and constant variance and $\theta \geq 0$ is known as the transition parameter of the ESTAR model that governs the speed of transition. We are now interested in testing the null hypothesis of $\theta = 0$ against the alternative $\theta > 0$. Under the null Y_t follows a linear unit root process, whereas it is nonlinear stationary ESTAR process under the alternative. However, the parameter γ is not identified under the null hypothesis. Kapetanios et al. (2003) use a first-order Taylor series approximation to $\{1-\exp(-\theta Y_{t-1}^2)\}$ under the null $\theta = 0$ and approximate Equation [1] by the following auxiliary regression:

$$\Delta Y_t = \xi + \delta Y_{t-1}^3 + \sum_{i=1}^{k} b_i \Delta Y_{t-i} + \nu_t , \quad \text{t = 1, 2,…., T} \qquad (2)$$

Then, the null hypothesis and alternative hypotheses are expressed as $\delta = 0$ (non-stationarity) against $\delta < 0$ (nonlinear ESTAR stationarity). The simulated critical values for different K are tabulated in Kapetanios et al. (2003) (Table 1 as of p.363). Table 2 reports the Kapetanios et al. (2003) nonlinear stationary test results indicating that both two series are integrated of order one.

<Insert Table 2 about Here>

For comparison, we further incorporate PP (Phillips and Perron, 1988), NP (Ng and Perron, 2001) and KPSS (Kwiatkowski et al., 1992) conventional unit-root tests into our empirical study.[4] [5] Panels A and B in Table 3 present the results of the non-stationary tests for the stock price and exchange rate from the PP, NP and KPSS tests. We find each data series is nonstationary in level but stationary in first difference, suggesting that all the data series are integrated of order one, i.e. I(1) series.

<Insert Table 3 about Here>

B. EG-ES Threshold Cointegration Tests

The findings of the I(1) series for both stock price and exchange rate enable us to proceed further test for long-run equilibrium relationship (cointegration) between these two variables. On the basis of the nonlinearity, we employ the threshold cointegration technique advanced by Enders and Granger (1998) and Enders and Siklos (2001). This is indeed a two-stage procedure. In the first stage, we estimate the cointegration equations as follows:

$$Y_{1t} = \alpha + \beta Y_{2t} + u_t \qquad (3)$$

where Y_{1t} and Y_{2t} are two I(1) series of the stock price and exchange rate, respectively. α and β are estimated parameters, and u_t is the disturbance term that may be serially correlated. The second stage focuses on the OLS estimates of ρ_1 and ρ_2 in the following regression:

$$\Delta u_t = I_t \rho_1 u_{t-1} + (1 - I_t)\rho_2 u_{t-1} + \sum_{i=1}^{l} \gamma_i \Delta u_{t-i} + \varepsilon_t \qquad (4)$$

where ε_t is a white-noise disturbance and the residuals, μ_t, in (3) are extracted to (4)

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[4] The test statistic for NP test is MZ_t in this paper.

[5] The null of KPSS test is testing for I(0), the null of the rest two tests (PP and NP) are testing for I(1).

to be further estimated. I_t is the Heaviside indicator function such that $I_t = 1$ if $u_{t-1} \geq \tau$ and $I_t = 0$ if $u_{t-1} \leq \tau$, where τ is the threshold value. A necessary condition for $\{\mu_t\}$ to be stationary is: $-2 < (\rho_1, \rho_2) < 0$. If the variance of ε_t is sufficiently large, it is also possible for one value of ρ_j to between –2 and 0 and for the other value to equal zero. Although there is no convergence in the regime with the unit-root (i.e., the regime in which $\rho_j = 0$), large realization of ε_t will switch the system into the convergent regime. Enders and Granger (1998) and Enders and Siklos (2001) both point out in either case, under the null hypothesis of no convergence, the F-statistic for the null hypothesis $\rho_1 = \rho_2 = 0$ has a nonstandard distribution. The critical values for this non-standard F-statistic are tabulated in their paper. Enders and Granger (1998) also show that if the sequence is stationary, the least squares estimates of ρ_1 and ρ_2 have an asymptotic multivariate normal distribution.

Model using (4) is referred to as Threshold Autoregression Model (TAR), where the test for threshold behavior of the equilibrium error is termed threshold cointegration test. Assuming the system is convergent, $\mu_t = 0$ can be considered as the long-run equilibrium value of the sequence. If μ_t is above its long-run equilibrium, the adjustment is $\rho_1 \mu_{t-1}$ and if μ_t is below its long-run equilibrium, the adjustment is $\rho_2 \mu_{t-1}$. The equilibrium error therefore behaves like a threshold autoregression. We can test the null hypothesis of $\rho_1 = \rho_2 = 0$ for the cointegration relationship and the rejection of this null implies the existence of cointegration between variables. The finding of $\rho_1 = \rho_2 = 0$ put it valuable to further test for symmetric adjustment (i.e., $\rho_1 = \rho_2$) by using a standard F-test. When adjustment is symmetric as $\rho_1 = \rho_2$, (4) converges the prevalent augment DF test (Dickey and Fuller, 1981). Rejecting both the null hypotheses of $\rho_1 = \rho_2 = 0$

and $\rho_1 = \rho_2$ imply the existence of threshold cointegration and the asymmetric adjustment.

Instead of estimating (4) with the Heaviside indicator depending on the level of μ_{t-1}, the decay could also be allowed to depend on the previous period's change in μ_{t-1}. The Heaviside indicator could then be specified as $I_t = 1$ if $\Delta u_{t-1} \geq \tau$ and $I_t = 0$ if $\Delta u_{t-1} \leq \tau$, where τ is the threshold value. According to Enders and Granger (1998), this model is especially valuable when adjustment is asymmetric such that the series exhibits more 'momentum' in one direction than the other. This model is termed Momentum-Threshold Autoregression Model (M-TAR). The TAR model can capture 'deep' cycle process if, for example, positive deviations are more prolonged than negative deviations. The M-TAR model allows the autoregressive decay to depend on $\Delta\mu_{t-1}$. As such, the M-TAR representation can capture 'sharp' movements in a sequence.

In the most general case, the value of τ is unknown, it needs to be estimated along with the value of ρ_1 and ρ_2. By demeaning the { μ_t } sequence, the Enders and Granger (1998) test procedure employs the sample mean of the sequence as the threshold estimate of τ. However, the sample mean is a biased threshold estimator in the presence of asymmetric adjustments. For instance, if autoregressive decay is more sluggish for positive deviations of μ_{t-1} from τ than for negative deviations, then the sample mean estimator will be biased upwards. A consistent estimate of the threshold τ can be obtained by using Chan's (1993) method of searching over possible threshold values to minimize the residual sum of squares from the fitted model. Enders and Siklos (2001) apply Chan's methodology to a Monte Carlo study to obtain the F-statistic for the null hypothesis of $\rho_1 = \rho_2 = 0$ when the threshold τ is estimated using Chan's procedure. The critical values of this non-standard

F-statistic for testing the null hypothesis of $\rho_1 = \rho_2 = 0$ are also tabulated in their paper. As there is generally no presumption as to whether to use TAR or M-TAR model, the recommendation is to select the adjustment mechanism by a model selection criterion such as the AIC or SBC.

Table 4 reports the results of the threshold cointegration test. From the AIC and SBC, we find the most preferable model for our adjustment mechanism is TAR model (where the threshold value of $\tau = -0.0616$ is found based on the Chan's (1993) method). Table 4 shows that both the null of no cointegration ($\rho_1 = \rho_2 = 0$) and symmetric adjustment ($\rho_1 = \rho_2$) are rejected, which imply the existence of threshold cointegration between the exchange rate and stock markets in Taiwan over this testing period.

<Insert Table 4 about Here>

C. Granger-Causality Tests Based on Threshold Error-Correction Model

Given the threshold cointegration found in previous section, we proceed to test the price transmissions using threshold error-correction model (TECM). The TECM can be expressed as follows (Enders and Granger, 1998; Enders and Siklos, 2001):

$$\Delta Y_{it} = \alpha + \gamma_1 Z_{t-1}^{+} + \gamma_2 Z_{t-1}^{-} + \sum_{i=1}^{k_1} \delta_i \Delta Y_{1t-i} + \sum_{i=1}^{k_2} \theta_i \Delta Y_{2t-i} + v_t \qquad [5]$$

where $\mathrm{Y_{it}} = (\mathrm{lsp_t}, \mathrm{ler_t})$, $Z_{t-1}^{+} = I_t \hat{u}_{t-1}$, $Z_{t-1}^{-} = (1 - I_t)\hat{u}_{t-1}$ such that $I_t = 1$ if $\mathrm{u_{t-1}} \geq -0.0616$, $I_t = 0$ if $\mathrm{u_{t-1}} \leq -0.0616$ and v_t is a white-noise disturbance. From the system, the Granger-Causality tests are examined by testing whether all the coefficients of $\Delta Y_{1,t-i}$ or $\Delta Y_{2,t-i}$ are jointly statistically different from zero based on a standard F-test and/or whether the γ_j coefficients of the error-correction are also significant. Since Granger-Causality tests are very sensitive to the selection of lag length, we use AIC criterion to determine the appropriate lag lengths and find both lag lengths of k_1 and k_2 are equal to one ($k_1 = k_2 = 1$).

Table 5 presents the results from our Granger-Causality tests based on the corresponding TECMs. They clearly show that there is a bidirectional feedback causality relationship between stock and exchange rate markets in the short-run. This result supports most of the previous literature that stock price and exchange rate are usually highly correlated. In terms of long-run situation, the feedback relationships between these two markets are further confirmed for both regions above and below the threshold level of -0.0616. This can be interpreted by the significant $\theta_1 = \gamma_1 = 0$ and $\delta_1 = \gamma_1 = 0$ for the higher region and $\theta_1 = \gamma_2 = 0$ and $\delta_1 = \gamma_2 = 0$ for the lower region, respectively. Focusing on the error correction term, we find that both higher and lower regions are shown to be significant in the stock market and insignificant in the exchange rate market. The nearly symmetric price transmissions between these two markets seem against the previous finding of asymmetric adjustment by rejecting $\rho_1 = \rho_2$. However, from the volume of the adjustment, we should still argue that the price transmissions between these two markets are asymmetric. The point estimates of adjustment coefficients given in Table 5 indicate that, within a day, the speed of adjustment in the stock price eliminates approximately 8.6% to restore to the equilibrium level when the error correction is below -0.0616. On the other hand, only 0.25% of the deviation can be restored to the equilibrium level in stock prices when the error correction is above -0.0616. These findings indicate that adjustments towards the long-run equilibrium relationship between stock price and exchange rate are faster when the previous disequilibrium level between these two assets is low than when it are high. However, though the speeds of adjustment in the lower region are faster in both markets, the phenomenon is significant only in the stock market. Furthermore, the F-statistic indicates that the null hypothesis of $\gamma_1 = \gamma_2$ (the coefficients of Z^+ and Z^- are equal) is rejected in the stock market, while it is not be rejected in the exchange rate market.

These empirical results indicate that price transmissions between these two markets are asymmetric. We find that the error-correction term is significant only in the stock market for both higher and lower regions with the threshold variable of -0.0616, and it insignificant for both regions in the exchange rate market. Our interpretation is that, over time, as measured by the error-correction term, in order to restore to the long-run relationship within system, it is from the stock prices that must bear the brunt of adjustment rather than the exchange rate for both regions below and above the threshold value of -0.0616. The different volumes of the adjustment coefficients explain that price transmissions between these two markets are asymmetric.

By way of contrast, Table 5 also reports the estimates of symmetric error-correction model. In the case of symmetric adjustment, we find a quite similar result to the above case of asymmetric adjustment.

In spite of the extra coefficients appearing in each equation of threshold model, the multivariate AIC selects threshold error-correction model over the symmetric error-correction model. The multivariate AIC is -10647.662 for the threshold error-correction model and -10645.952 for the symmetric error-correction model.

<Insert Table 5 about Here>

IV. Conclusion

Employing the threshold error-correction model, we investigate the asymmetric causal relationship between stock price and exchange rate in Taiwan using both the daily closing data running from 1994 to 2004. The results from Granger-Causality tests based on corresponding threshold error-correction model (TECM) clearly point out a bidirectional feedback causality relationship between stock and exchange rate markets both in the short-run. In terms of long-run situation, the feedback relationships between these two markets are further confirmed for both regions above and below the threshold level. Furthermore, we find asymmetric price transmissions between these two markets in the long run that adjustments towards the long-run equilibrium relationship between stock price and exchange rate are faster when the previous disequilibrium level between these two assets is low than when it are high. However, though the speeds of adjustment in the lower region are faster in both markets, the phenomenon is significant only in the stock market. These findings ought to be made readily available to individual investors and financial institutions holding long-term investment portfolios in these two asset markets for their likely implications today.

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Table 1. Summary Statistics of Stock Price and exchange rate

	Stock Price	Exchange Rate
Mean	6449.74	30.997
SD	1419.58	3.179
Maximum	10202.20	35.168
Minimum	3446.26	25.141
Skewness	0.49	-0.33
Kurtosis	2.53	1.52
J-B N Test	142.34***	325.375***
L-B (Q=4)	18.50***	67.96***
L-B (Q=4)-Square	234.75***	141.58***

Notes: 1. SD denotes standard error.

2. The standard errors of the skewness and kurtosis are $(6/T)^{0.5}$ and $(24/T)^{0.5}$, respectively.

3. J-B N Test denotes the Jarque-Bera normality test.

4. L-B (Q=k) represents the Ljung-Box test for autocorrelation up to k lags.

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

Table 2. Unit Root Test based on KSS (2003) Approach

	t Statistic on $\hat{\hat{\delta}}$
S	-1.9514(2)
EX	-1.7948(1)

Note: The numbers in the parentheses are the appropriate lag lengths selected by MAIC (modified Akaike information criterion) suggested by Ng and Perron (2001).

Table 3. PP , NP and KPSS Unit Root Tests

	Panel A: PP		Panel A: NP		Panel B: KPSS (η_μ)	
	level	difference	level	difference	level	difference
S	-2.0000(4)	-48.9477(7)***	-2.0036(4)	-22.6410(7)***	4.8573(5) ***	0.0674(6)
EX	-0.5677(3)	-44.1675(3)***	-0.9452(5)	-19.3009(6)***	4.2361(6) ***	0.0962(6)

Notes: 1. The number in the parentheses of NP are the appropriate lag lengths selected by MAIC (modified Akaike information criterion) suggested by Ng and Perron (2001), whereas the number in the parentheses of PP and KPSS are the optimal bandwidth decided by Bartlett kernel of Newey and West (1994).

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

3. Critical values for the KPSS test are taken from Kwiatkowski et al. (1992).

4. The test statistic for NP is MZ_t .

Table 4. Threshold Cointegration Tests (Enders and Granger (1998) Approach)

$\hat{\rho}_1$	$\hat{\rho}_2$	$\hat{F}_C$	$\hat{F}_A$	l
-0.0025(-1.8057)*	-0.0846(-3.1859)***	6.6877**	9.5367***	4

Notes: 1. *, **, and *** denote significance at the 1%, 5%, and 10% levels, respectively. Lag-length (l) selection is based on the procedure advanced by Perron (1989).

2. t statistics are in parentheses. $\hat{F}_C$ and $\hat{F}_A$ denote the F-statistics for the null hypothesis of no cointegration and symmetry. Critical values are taken from Enders and Siklos (2001).

3. Based on AIC and SBC, model is specified as TAR model where the threshold value of $\tau = -0.0616$.

Table 5. Estimates of the Error-Correction Models

	Asymmetric		Symmetric	
	S	EX	S	EX
Constant	-0.0000(-0.0792)	0.0001(1.2169)	-0.0000(-0.0547)	0.0001(1.2128)
S(-1)	0.0458(2.3381)**	-0.0109(-3.3962)***	0.0439(2.2381)**	-0.0108(-3.3814)***
EX (-1)	-0.3496(-2.9486)***	0.1435(7.3894)***	-0.3511(-2.9558)***	0.1435(7.3925)***
Z^{+}_{t-1}	-0.0025(-1.7626)*	0.0000(0.1247)		
Z^{-}_{t-1}	-0.0861(-3.2139)***	0.0024(0.5458)		
ECT_{t-1}			-0.0027(-1.9204)*	0.0000(0.1523)
$H_0 : \theta_1 = \gamma = 0$			6.2092***	
$H_0 : \delta_1 = \gamma = 0$				5.7176***
$H_0 : \theta_1 = \gamma_1 = 0$	5.8967***			
$H_0 : \theta_1 = \gamma_2 = 0$	9.5481***			
$H_0 : \delta_1 = \gamma_1 = 0$		5.7670***		
$H_0 : \delta_1 = \gamma_2 = 0$		5.8611***		
H_0 :(S) $\gamma_1 = \gamma_2$	9.7233**			
H_0 :(EX) $\gamma_1 = \gamma_2$		0.2902		
AIC	-1030.633	-10647.662	-1022.909	-10645.952

Notes: 1. *, **, and *** denote significance at the 1%, 5%, and 10% levels, respectively. t statistics are in parentheses.

2. Threshold Error-Correction Model:

$$\Delta Y_{it} = \alpha + \gamma_1 Z^{+}_{t-1} + \gamma_2 Z^{-}_{t-1} + \sum_{i=1}^{k_1} \delta_i \Delta Y_{1t-i} + \sum_{i=1}^{k_2} \theta_i \Delta Y_{2t-i} + v_t$$

where $\mathrm{Y}_{\mathrm{it}} = (\mathrm{lsp}_{\mathrm{t}}, \mathrm{ler}_{\mathrm{t}})$, $Z^{+}_{t-1} = I_t \hat{u}_{t-1}$, $Z^{-}_{t-1} = (1 - I_t)\hat{u}_{t-1}$ such that $I_t = 1$ if $\mathrm{u}_{t-1} \geq -0.0616$, $I_t = 0$ if $\mathrm{u}_{t-1} \leq -0.0616$ and v_t is a white-noise disturbance.

3. Symmetric Error-Correction Model: $\Delta Y_{it} = \alpha + \gamma \hat{u}_{t-1} + \sum_{i=1}^{k_1} \delta_i \Delta Y_{1t-i} + \sum_{i=1}^{k_2} \theta_i \Delta Y_{2t-i} + v_t$

4. S and EX represent stock price index and exchange rate, respectively.