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Abstract

Exponential Smooth Transition Autoregressive (ESTAR) model is widely adopted in the exchange rate study as its symmetrical distribution matches that of the symmetrical exchange rate adjustment behaviour. In contrast, another specification of STAR model, namely the LSTAR (logistic STAR) model is discarded by most researchers *in priori* in their exchange rate modeling exercises due to its undesired property of being asymmetry. This study is the first of its kind in examining the validity of this hypothesis that the ESTAR exchange rate model is superior to LSTAR exchange rate model on the basis of forecasting accuracy. Based on the experience of the adjustment process of two nominal exchange rates, we find that the hypothesis is merely theoretical since we fail to provide consistent empirical evidence in favour of the null hypothesis. This warrants us that we need not be too pessimistic on the usage of LSTAR model in exchange rate study. In our effort to rekindle the usage of LSTAR model, we further reparameterized the original version into the so-called absolute version, which has symmetrical distribution properties, in accordance with the well-known symmetrical adjustment process of exchange rate. The resulting ALSTAR model has proven to be a more promising model in the sense that it has improved significantly from its original version as well as the ESTAR model, which has thus far been deemed the most appropriate nonlinear exchange rate model.

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Keywords: LSTAR, ESTAR, forecasting accuracy, nonlinear, exchange rate

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1. Introduction

A number of empirical studies have documented that exchange rate behavior may be well characterized by the Smooth Transition Autoregressive (STAR) process (Taylor and Sarno, 1998; Sarantis, 1999; Taylor and Peel, 2000; Sarno, 2000; Baum et al., 2001; Guerra, 2001; Liew et al., 2004). STAR model is a nonlinear econometric model that is able to capture the movement of exchange rate, which adjusts every moment but the speed of adjustment varies with the size of exchange rate deviations. The STAR model for a mean corrected variable of interest, z_{t-d} may be parameterized as:

$$z_t = \sum_{i=1}^{p} \beta_i z_{t-i} + \left(\sum_{i=1}^{p} \beta_i^* z_{t-i}\right) \mathrm{F}(z_{t-d}) + \varepsilon_t \tag{1}$$

where β_i and β_i^*, i = 1, …, p are autoregressive parameters, F(·) is the transition function depending on the lagged level, z_{t-d} where d is known as the delay length or delay parameter, and ε_t is a white noise with zero mean and constant variance.

Two forms of transition function given in Teräsvirta (1994) are the logistic function

$$\mathrm{F}(z_{t-d}) = [\, 1 - \exp(-\gamma^2 \, z_{t-d})]^{-1}, \tag{2}$$

and the exponential function

$$\mathrm{F}(z_{t-d}) = 1 - \exp[-\gamma^2 (z_{t-d})^2] \tag{3}$$

where γ^2 stands for the transition parameter, which measures the speed of adjustment.

A plot of these typical transition functions with respect to the delay parameter is depicted in Figure 1. It is clear from the Figure 1 that logistic transition function has a S shape distribution (top panel), while exponential transition function has symmetrical inverted-bell shape distribution (middle panel). Note that values of these functions lie between 0 and 1; see Teräsvirta (1994) for theoretical issues on these functions.

STAR model (1) with specification (2) is known as ESTAR or exponential STAR model, whereas with specification (3) is termed LSTAR or logistic STAR model. These two models have quite different empirical implication of dynamic exchange rate behaviour. The LSTAR model describes the asymmetrical nonlinear adjustment process, while the ESTAR model suggests symmetrical nonlinear adjustment process (Sarantis, 1999). LSTAR is a monotonic increasing function of z_{t-d} and yields asymmetric adjustment towards equilibrium (top panel, Figure 1). However, the theoretically assumption that exchange rate adjustment is symmetric implies LSTAR model as inappropriate for modelling exchange rate movements. As such, this model has been neglected in the exchange rate study and most relevant studies discard LSTAR model and regard *a priori*

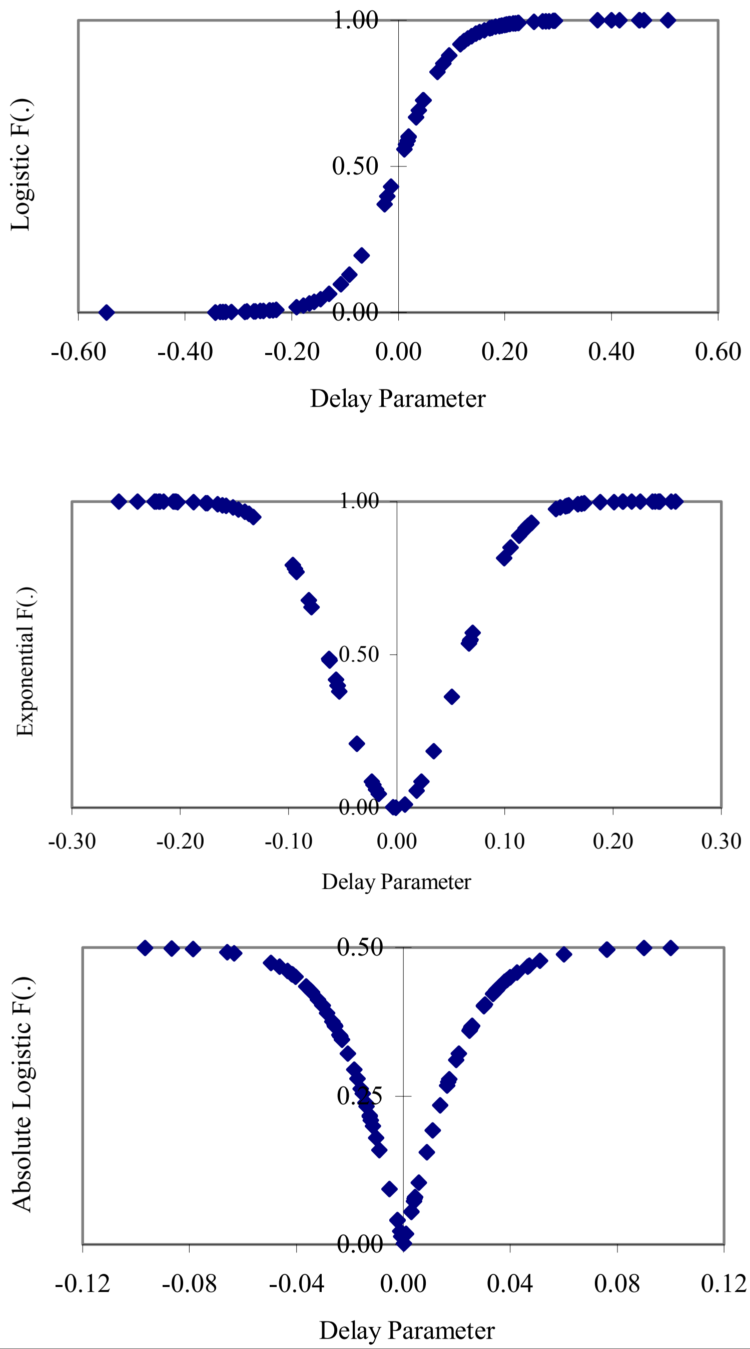
ESTAR model as the correct represent of exchange rate (for instance, Taylor and Peel; 2000 and Sarno, 2000)[1]. In order to revitalize the use of LSTAR model, we propose to reparameterize LSTAR model, with logistic function specified as

$$\mathrm{F}(z_{t-d}) = [1 + \exp(-\gamma^2 \,|\, z_{t-d} \,|)]^{-1} - ½ \qquad (4)$$

where | · | implies absolute value.

We refer to the resulting model as ALSTAR (absolute LSTAR) to differentiate it from the original specification (2). The absolute logistic transition function (4) allows a V-shaped (similar to inverted bell-shaped, but with sharp vertex) symmetry adjustment process of the exchange rate towards the mean of z_t that is zero in our case. This logistic F(·) is bounded between zero and one-half, with F(·) → 0 when $\gamma^2 \rightarrow 0$ and F(·) → ½ when $\gamma^2 \rightarrow \infty$. The plot of our proposed absolute transition function is given in the lower panel of Figure 1. The V shape distribution, with values between 0 and 0.5 are explicitly shown in Figure 1. We will show later, that this specification of LSTAR is also capable of describing the symmetrical behavior in exchange rates.

[1] We note here that, to date, no published empirical study has been performed to verify the claim on this issue.



Note: Values in the plots are hypothetical.

Figure 1: Theoretical shapes of various transition functions

The objectives of this paper are: First, to evaluate the forecasting performance of LSTAR model with respect to the ESTAR model. With this approach, effectively we are providing a platform to examine how far the hypothesis that ESTAR model is more relevant in characterizing the exchange rate adjustment process than the LSTAR model could be justified. Second, to evaluate our proposed ALSTAR model using linear autoregressive (AR) model, LSTAR model and ESTAR model as benchmark. These objectives could be accomplished based on the mean square error (*MSE*) and the robustness of this criterion is subjected to Meese and Rogoff (1988) test.

This paper proceeds as follows. Our research methodology is described in Section 2, whereas results of this study and discussions are presented in Section 3. Our conclusions are given in the final section.

2. Methodology

Data

The data employed in this study includes yen-based nominal exchange rates (domestic price of foreign money) and relative prices (proxied by the ratio consumer price indices). Quarterly data series from two ASEAN neighboring countries, namely Malaysia and Thailand are collected from the *International Financial Statistics*, published by International Monetary Fund. Our sample period ranges from 1980:1 to 2001:2. The whole sample is subdivided into 2 portions. The first portion (1980:1 to 1997:2) is used for model estimation, while the rest are kept for assessing the out-sample forecast performance of the studied models.

Standard augmented Dickey Fuller unit root has been performed on these data and results (available upon request) reveal that they are all integrated of order one. In addition, the exchange rates involved are found cointegrated with their respectively relative prices (ratio of domestic price to foreign price) based on the commonly used Johensen and Juselius procedure (available upon request). This is supportive of the long run purchasing power parity hypothesis, which implies that exchange rates adjust towards their equilibrium Purchasing Power Parity (PPP) values in the long run, although deviations may occur due to transaction costs in the short run (Dumas, 1992). The theoretical no-arbitrage model of Dumas that exchange rates adjustment are nonlinear in nature may be tested by performing the linearity test of as described in Luukkonen et al. (1988) on the deviations (in this study, z_t) of exchange rate, from the equilibrium level.

Linearity Test

We employ auxiliary regression of the following specification

$$z_t = \alpha_0 + \sum_{i=1}^{p}(\alpha_i z_{t-d} + \alpha_i^* z_{t-i} z_{t-d} + \delta_i^* z_t z_{t-d}^2) + \tau^* z_{t-d}^3 + \omega_t \qquad (5)$$

The null hypothesis to be tested is that

$$H_0: \alpha_i^* = \delta_i^* = \tau^* = 0;\ i = 1, \ldots, p \qquad \text{(linear model is correct)} \qquad (6)$$

where the optimal lag length, p and the delay parameter, d have to be determined in advance[2]. This null hypothesis may be tested using the Lagrange Multiplier (*LM*) type test statistic as described in Luukkonen et al. (1988); see Teräsvirta (1994) also. Rejection of null hypothesis (6) implies exchange rate adjusts nonlinearly as characterized by the STAR. One may proceed on a subset of tests if the objective is to check whether LSTAR or ESTAR is the correct specification. Nonetheless, there is a possibility that both models are appropriate. In such case, Escribano and Jorda (2001) suggest to choose the one with smaller marginal significance value of *LM* statistic. However, the selection may be postponed to the final stage of model evaluation via certain criteria (Teräsvirta, 1994). This study focuses on forecasting performance; hence, the chose of model specification is not our concern here.

Forecasting performance criteria

The overall in-sample (65 quarterly observations) and out-sample performance of the estimated absolute LSTAR model over the forecast horizon of n =14 over the period 1997:3 to 2000:4 are evaluated by taking the linear AR (p) and ESTAR models as the benchmark[3]. The criterion involved is the ratio of forecast error measured in mean square error (MSE), with the forecast error of benchmark model as denominator. We compute the Meese and Rogoff (1988) MR statistic to check the statistical significance of the MSE criteria. MR for finite sample is given by

[2] Following Liew et al. (2004), p is determined by AICC, the Akaike information criterion (biased corrected version) and for $1 \leq d \leq 12$, the optimal value is the one that provides the smallest marginal significance value of the *LM* test statistic.
[3] Tong and Lim (1980) points out that one of the requirements for nonlinear time series model is that its overall prediction performance should be an improvement upon the linear model.

$$MR = \frac{\bar{s}_{UV}}{\sqrt{\frac{1}{n^2}\sum_{j=1}^{n} u_j^2 v_j^2}} \overset{asy}{\sim} \text{N }(0, 1) \tag{7}$$

where U and V are transformed functions of forecast errors of two rival models; $\bar{s}_{UV}$ is the sample covariance of means of U and V and is approximated by $\frac{1}{n}\sum_{j=1}^{n}(u_j - \bar{u})(v_j - \bar{v})$ where $\bar{u} = \frac{1}{n}\sum_{j=1}^{n} u_j$ and $\bar{v} = \frac{1}{n}\sum_{j=1}^{n} v_j$ with $u_j = e_{1j} - e_{2j}$ and $v_j = e_{1j} + e_{2j}$ in which e_{ij}, $i = 1, 2$ is the j^{th} forecast error of model i; and n is the number of forecasts.

The null hypothesis of *MR* statistic, which states that cov $(U, V) = 0$ implies evaluating whether $MSE_1 = MSE_2$. If *MR* statistics is significantly different from the critical values (from Z table if n is large enough, t table otherwise), the improving in forecasting accuracy in model 1 over model 2 in the *MSE* ratio will then be statistically significant.

3. Results and Discussions

Linearity Test

The results of linearity tests suggest that the null of linearity has been rejected, at standard significance levels, in favor of both the LSTAR and ESTAR specifications.[4]

[4] Using different sample period (1968:1 to 2001:2), linearity in the Asian exchange rate (including MYR/JPY and THB/JPY) adjustment has also been rejected in Liew et al. (2004). However, the LSTAR model as well as its forecasting performance is not considered in it.

Thus LSTAR model with p = 1 and d = 4 is an appropriate representation of the ringgit adjustment process. One the other hand, this series could be characterized by ESTAR model with p = 1 and d = 2 as well. As for the adjustment of the baht, it is described by both LSTAR model with p = 3 and d = 1 and ESTAR model with p = 3 and d = 5. Residual diagnostic by the Ljung Box portmanteau Q statistic shows that all models are free from serial correlation, which is normally associated with autoregressive model. These results are summarized in Table 1.

Table 1

Linearity Test Results

Exchange Rate Deviations	p	Marginal Significance Values					
		d_{LS}	LM_{LS} Test	Q (20)	d_{ES}	LM_{ES} Test	Q (20)
MYR/JPY	1	4	0.056	0.219	2	0.025	0.445
THB/JPY	3	1	0.016	0.579	5	0.001	0.995

Notes: Lagrange Multiplier (LM) test tests for the null hypothesis of H_0: Linear model is correct. Rejection of H_0 by the LM_{LS} (LM_{ES} Test) test implies the presence of nonlinearity in favour of LSTAR (ESTAR) model. d_{LS} (d_{LS}) stands for optimal delay lag length that minimizes the marginal significance value of LM_{LS} (LM_{ES}) test. Ljung-Box Q statistic [Q (20)] detects the presence of serial correlation in the model's residuals up to 20 lags, if any.

Estimated Models

The estimated models are tabulated in Table 2. As serial correlation is a major problem in any time series model, we include the Ljung Box Portmanteau (Q) test to detect the presence of serial correlation. The p-values of these Q statistics indicate that all estimated models are free from serial correlation problem. Thus, these models are appropriate in characterizing the adjustment process of MYR/JPY and THB/JPY towards the long-run PPP equilibrium. As a measure to check whether the nonlinear specification is correct, we employ the overall significance F test. The null hypothesis of this F test is that the linear specification is correct. Results show that the joint effect of the nonlinear parameters and the transition parameter in each model is significance at standard levels, indicating that the linear specification has been rejected in favour of the STAR specification. In addition, we find that STAR model yields smaller variance than their linear counterpart, indicating that it potential to produce smaller forecast error than the AR model (Teräsvirta and Anderson, 1993). The last two finding confirms that the adjustment process of MYR/JPY and THB/JPY towards the long-run PPP equilibrium is of nonlinear nature. Thus, this study has provided further empirical evidence on the existence of the nonlinear dynamic in the context of ASEAN foreign exchange market, in accordance to Lim et al. (2002).

The empirical distributions of various transition functions are given in Figure 2. The top panel depicts the logistic functions for the MYR/JPY (left) and THB/JPY (right) rates. This function is a monotonic increasing function of exchange rate deviations as expected, with speed of transition varies across exchange rates. In particular, the MYR/JPY adjustment is a smooth and steady process, whereas the THB/JPY adjustment is speedy and abrupt. The V shape distribution of absolute transition function is plotted at the middle panel of Figure 2. This figure shows that there are satisfactorily equal amount of negative and positive adjustments around the equilibrium level (indicated by the zero value of deviation). This finding verified our claim that the symmetrical adjustment process of exchange rates could be well characterized by the absolute LSTAR model. Finally, the empirical distributions of exponential functions, which are in line with most related studies, are given in the bottom panel of Figure 2. This is not surprising, as it has been well documented that this function fitted the symmetrical adjustment of exchange rate nicely.

Table 2

Estimated STAR Models

Parameter	LSTAR Model		Absolute LSTAR Model		ESTAR Model	
	MYR/JPY	THB/JPY	MYR/JPY	THB/JPY	MYR/JPY	THB/JPY
β_1	0.85×10^{0} $(0.13\times10^{0})^{a}$	-0.57×10^{4} $(0.67\times10^{1})^{b}$	-0.11×10^{1} $(0.11\times10^{0})^{a}$	0.15×10^{1} $(0.22\times10^{0})^{a}$	0.14×10^{1} (0.35×10^{1})	0.22×10^{1} $(0.77\times10^{0})^{a}$
β_2	—	0.30×10^{5} $(0.10\times10^{5})^{b}$	—	-0.20×10^{-1} $(0.35\times10^{1})^{b}$	—	0.10×10^{-1} $(0.10\times10^{-4})^{a}$
β_3	—	-0.23×10^{5} $(0.96\times10^{4})^{b}$	—	0.20×10^{0} (0.25×10^{1})	—	-0.01×10^{-1} $(0.10\times10^{-4})^{a}$
β_1^*	-0.10×10^{-1} (0.14×10^{0})	0.11×10^{5} (0.12×10^{5})	-0.14×10^{4} (0.10×10^{4})	-0.16×10^{3} (0.25×10^{3})	-0.60×10^{0} (0.35×10^{1})	-0.13×10^{1} $(0.76\times10^{0})^{b}$
β_2^*	—	-0.61×10^{5} $(0.20\times10^{5})^{b}$	—	-0.10×10^{4} (0.63×10^{3})	—	-0.16×10^{1} (0.69×10^{0})
β_3^*	—	0.47×10^{5} $(0.19\times10^{5})^{b}$	—	0.73×10^{3} (0.53×10^{3})	—	-0.40×10^{-2} (0.46×10^{-1})
γ^2	0.44×10^{1} $(0.10\times10^{-4})^{a}$	0.17×10^{3} $(0.49\times10^{2})^{b}$	0.18×10^{-3} $(0.10\times10^{-4})^{a}$	0.60×10^{-1} $(0.10\times10^{-4})^{a}$	0.39×10^{2} $(0.35\times10^{1})^{a}$	0.27×10^{3} $(0.11\times10^{1})^{a}$
Diagnostic Checkings						
V_{NL}/V_L	0.959	0.932	0.968	0.813	0.883	0.837
p (F test)	0.060	0.024	0.039	0.017	0.030	0.011
p (Q test)	0.262	0.876	0.264	0.969	0.303	0.987

Notes: Figures in parentheses are standard errors of estimated parameters. Superscript [a] and [b] imply significant at 5% and 10% respectively. V_{NL}/V_L stands for ratio of residual variance of nonlinear model to that of linear model. *p* (·) stands for *p*-value of the implied test statistic. F test tests for the overall significance of the nonlinear parameters. Q test is the Ljung-Box Portmanteau serial correlation test.

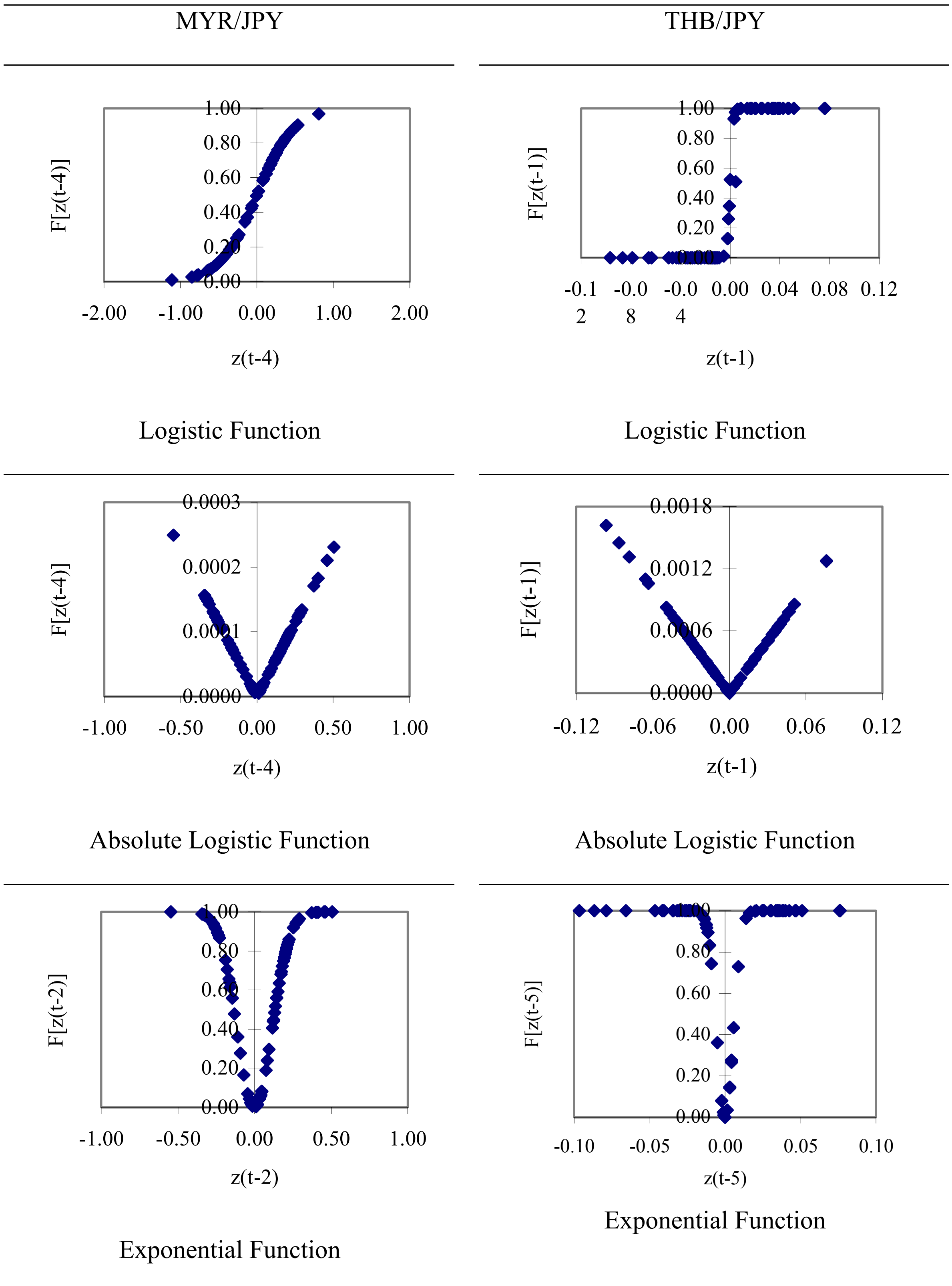


Figure 2: Plots of estimated transition functions

Forecast Accuracy

Our first forecasting accuracy comparison exercise is done using AR model as benchmark. By observing the *MSE* ratio, it is clear that all the nonlinear STAR models have out-predicted the linear AR models in the context of in-sample forecasting (Table 3). This finding is not by chance as the *MR* statistic has verified that it is significant at 10% or better. One implication of this finding is that STAR model, rather than the conventional AR model could better explain the past exchange rate behavior. We note here that apart form being able to explain the past, a good model should also have the ability to predict the future with satisfactory accuracy. This scenario is observed in a number of related studies and is once again experienced in this current study[5]. More specifically, we find that none of the outstanding performance of LSTAR models (for MYR/JPY and THB/JPY) can be extended to the out-sample horizon[6]. As for the ESTAR model, results are mixed: The ESTAR MYR/JPY model does continue to be more excellence than its linear counterpart, but the ESTAR THB/JPY model shows reverse result. Meanwhile, the ALSTAR model seems to be the only promising model that carries over its outstanding forecasting ability from the in-sample horizon to the out-sample horizon. This conclusion is drawn from the fact that ALSTAR model remains the only model that out-predicted its linear counterpart significantly in predicting both the future behavior of MYR/JPY and THB/JPY adjustments. Hence, while LSTAR model has been

[5] For instance, Choo and Ahmad 1999; Tashman, 2000; Liew and Shitan, 2002 documented that models that explained the past best need not necessarily be the best forecasting model.

[6] It is worth pointing out that if we were to based our model selection criterion on out-sample performance (which is strongly recommended by Tashman, 2000), this finding is in line with the previous studies that LSTAR model is inadequate in characterizing the exchange rate adjustment behaviour (Taylor and Peel; 2000 and Sarno, 2000).

discarded, in the past, due to its inabilities to characterize the symmetrical exchange rate adjustment behavior, this study has provided an improved version, namely the absolute LSTAR model, which forecasting performance has been proven promising. This claim will be more obvious by conducting the next exercise.

Table 3

Overall Forecasting Accuracy with AR as Benchmark

Exchange Rate	*MSE* Ratio (*MR* Test Statistics)		
	LSTAR / AR	ALSTAR / AR	ESTAR / AR
	In-Sample (65 quarters)		
MYR/JPY	0.929 (1.978)[b]	0.146 (1.845)[b]	0.429 (1.541)[b]
THB/JPY	0.399 (1.520)[a]	0.381 (1.477)[a]	0.523 (1.569)[b]
	Out-Sample (14 quarters)		
MYR/JPY	1.008 (4.132)[b]	0.382 (6.707)[b]	1.562 (5.561)[b]
THB/JPY	1.104 (7.721)[b]	0.438 (6.466)[b]	0.588 (6.385)[b]

Notes: *MR* tests the null hypothesis of "equal accuracy" against two-sided alternative of "unequal accuracy" in terms of *MSE* ratio. The 10%, 5% and 1% critical values are 2.326, 1.645 and 1.282 respectively. Superscripts [a] and [b] denote significant at 10% and 5% level or better, respectively.

The second forecasting accuracy comparison exercise aims is done within the context of various STAR models. The results of comparison are tabulated in Table 4. From Table 4, the original version of LSTAR model is at most comparable to the ESTAR model in both the in- and out-sample forecasting horizons. Table 4 also reveals that absolute version of LSTAR has significantly improved over its original version, in all forecasting horizons. This finding is not surprising since the former, but not the latter could account for well-documented symmetrical exchange rate adjustment. Our most striking result is that ALSTAR model even significantly beaten the commonly accepted ESTAR exchange rate model in the sense that ALSTAR model has shown its potential in predicting the future exchange rate adjustment behavior (as far as MYR/JPY and THB/JPY is concerned) with better accuracy than the ESTAR model, apart from giving better explanation for the past adjustment.

Table 4

Comparison of Overall Forecasting Accuracy among STAR Models

Exchange Rate	*MSE* Ratio (*MR* Test Statistics)		
	ALSTAR / LSTAR	LSTAR / ESTAR	ALSTAR / ESTAR
In-Sample (65 quarters)			
MYR/JPY	0.157 (1.844)[b]	1.896 (2.074)[b]	0.943 (2.004)[b]
THB/JPY	0.955 (1.915)[b]	0.763 (1.923)[b]	0.729 (1.839)[b]
Out-Sample (14 quarters)			
MYR/JPY	0.379 (7.392)[b]	0.645 (7.360)[b]	0.244 (4.870)[b]
THB/JPY	0.396 (5.603)[b]	1.878 (5.789)[b]	0.745 (9.566)[b]

Note: See Table 3.

4. Conclusions

The advanced econometric STAR model has been widely applied in the exchange rate study due to its capability in characterizing the nonlinear exchange rate adjustment behaviour. To date, two specifications, namely the LSTAR (logistic STAR) and the ESTAR (exponential STAR) have thus far been proposed. The latter is preferable since its symmetrical distribution matches that of the symmetrical exchange rate adjustment behaviour. In contrast, most researchers discard the former *in priori* in their exchange rate modeling exercises due to its undesired property of being asymmetry. Nevertheless, to date, not a single published article has provided empirical evidence on the hypothesis that ESTAR is better than LSTAR. This study examines the validity of this hypothesis on the basis of forecasting accuracy. Based on the experience of the adjustment process of two nominal exchange rates, we fail to provide consistent results in favour of the null hypothesis. This warrants us that we need not be too pessimistic on the usage of LSTAR model in exchange rate study. In our effort to rekindle the usage of LSTAR model, we further reparameterized the original version into the so-called absolute version, which has symmetrical distribution properties, in accordance with the well-known symmetrical adjustment process of exchange rate. The resulting ALSTAR model has proven to be a more promising model in the sense that it has improved significantly from its original version as well as the ESTAR model, which has thus far been deemed the most appropriate nonlinear exchange rate model.

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