EGC, Economics Programme
School of Social Sciences
Nanyang Technological University
14 Nanyang Drive
Singapore 637332

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Fangli YAN and Paul S.L. YIP

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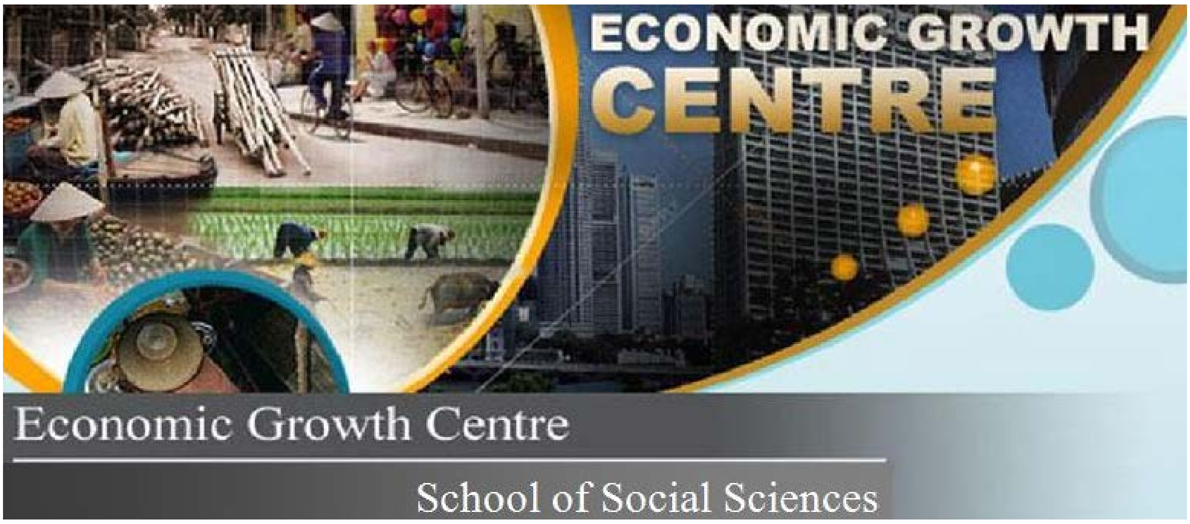
HSS-04-90A
Tel: +65 6790-6073
Email: D-EGC@ntu.edu.sg



Nonlinear Adjustment and Exchange Rate Policy: Lessons from Singapore for other Small Open Economies

by

Fangli Yan,
School of Economics and Finance, Xi'an Jiaotong University, China

and

Paul S. L. Yip,
Department of Economics, Nanyang Technological University, Singapore

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Abstract

This paper uses a Smooth Transition Autoregressive (STAR) regression to estimate the adjustment speed of exchange rate in a small open economy, in which exchange rate policy plays an important role in facilitating macroeconomic adjustment and controlling inflation. The result of our estimation suggests that the adjustment speed in the selected economy (Singapore) is faster than estimates reported in the literature. The relatively fast adjustment speed and the other related successes in Singapore could make its system a role model for many other small open economies. In addition, we found evidence of the Harrold-Balassa-Samuelson (HBS) effect and our results support Lothian and Taylor's (2008) argument that failure to include the effect in the estimation would lead to biased estimate in the adjustment speed. Thus, one should be cautious of the significant portion of past empirical studies that did not incorporate the HBS effect in their estimations. Future empirical studies should include the effect in the estimations and tests, or at least test for the absence of the effect before excluding it from the estimations. Finally, we found evidence that exchange rate policy is neutral in the long-run and non-neutral in the short-run in the selected economy. We then discussed the policy implications of this finding.

Keywords: Smooth Transition Autoregressive models, nonlinear adjustment and mean-reversion speed, exchange rate policy, Purchasing Power Parity, long-run neutrality, short-run non-neutrality.

JEL Classification: F41, F31, C22.

1. Introduction

This paper uses a Smooth Transition Autoregressive (STAR) regression to estimate the adjustment speed of exchange rate in a small open economy, in which exchange rate policy plays an important role in facilitating macroeconomic adjustments and controlling inflation. As pointed out by Taylor, Peel and Sarno (2001), Kilian and Taylor (2003), Taylor (2004) and Emirmahmutoglu and Omay (2014), heterogeneity of opinion in the foreign exchange market concerning the equilibrium level of exchange rate, exchange rate policy or central bank intervention in the foreign exchange market, speculative attack on currencies, the presence of target zones, and transaction costs in international arbitrages would result in nonlinear mean reversion speed of exchange rate. Thus, a nonlinear STAR model should be used for the estimation in the small open economy. With the appropriate tool, our first goal is to estimate how fast the real effective exchange rate (REER) would adjust to the equilibrium level. This is important as it is related to the adjustment cost in terms of output losses or inflation if there is an exogenous shock that necessitates an adjustment in the economy's real exchange rate.

To achieve the above and the next three research goals, Singapore is chosen for the study because of the following reasons. Firstly, it is a well-managed small open economy, which could make it a role model for many other small open economies (see the literature mentioned in footnote 2). Secondly, as explained in Yip (2005), its Central Provident Fund system and exchange rate system arrangements ensure that it would have a very good control on its nominal effective exchange rate (NEER), and it has opted to use exchange rate policy to achieve its internal balance (i.e., full employment with low inflation). That is, as a small open economy, Singapore finds that exchange rate policy instead of monetary policy would have greater and more direct influence on its exports and imported inflation, and hence output and overall inflation [see Monetary Authority of Singapore (MAS, 2000 and 1992/93) and Teh and Shanmugaratnum (1992)].[1] Thus, a proper study on how well Singapore uses its exchange rate policy

[1] Note that Singapore has opted for free capital mobility in order to become a global financial center. According to the Doctrine of Impossible Trinity, the choice of free capital mobility would mean that Singapore could only choose either independent exchange rate policy or independent monetary policy, but not both (Yip, 2005). Thus, Singapore's choice of independent exchange rate policy would mean that there would be no independent monetary policy in the economy.

would give important insight on the choice of exchange rate system for many other small open economies.[2]

As shown in Figure 1, Singapore's NEER has been appreciating with only occasional depreciations since the mid-1980s. Thus, our second goal is to check whether the effect of the persistent nominal exchange rate appreciation on REER would be completely offset by a lower domestic inflation when compared with the weighted average of inflation in its 15 largest trading partners after appropriate adjustment in the productivity growth differential. If the answer is yes, then the effect of the persistent nominal exchange rate appreciation on Singapore's relative price competitiveness would be neutral in the long run, and the long-term benefit of Singapore's choice of persistent but gradual appreciation is a domestic inflation lower than foreign inflation. In such a case, Singapore's exchange rate policy and its achievements would provide valuable lessons for other small open economies with sound economic fundamentals. If the answer is no, then the persistent appreciation will hurt Singapore's relative price competitiveness, and the policy implication would be very different from the current policy adopted by the Singapore monetary authority (i.e., this would imply a serious mistake in Singapore's exchange rate policy).

In addition to the second goal on the test of long-run neutrality of nominal exchange rate appreciation, our third goal is to check for evidence of short-run non-neutrality of nominal exchange rate changes in the small open economy. If there is short-run non-neutrality, then any nominal exchange rate changes beyond (below) the expected long-run appreciating path would cause a temporary rise (fall) in the real effective exchange rate and hence a reduction (increase) in aggregate demand. In such a case, there will be a role for the exchange rate policy to achieve internal balance through macroeconomic fine-tuning. On the other hand, if it is neutral even in the short run, then any exchange rate changes beyond or below the expected long-run appreciating path will be immediately offset by an opposite change in domestic price, which would mean no change in the real effective exchange rate and aggregate demand

[2] As documented in the literature of Singapore's exchange rate system, Singapore is able to achieve a gradually appreciating NEER with a substantial current account surplus (Yip, 2005) and a domestic inflation rate that is lower than that of its top 15 trading partners (Yip, 2003 and 2002), a lower volatility in its nominal effective exchange rate than that in the major economies with a floating exchange rate system (Yip, 1996), and a lower volatility of interest rate than that in Hong Kong (Tse and Yip, 2003 and 2006). Together with the result of a relatively fast adjustment speed of real exchange rate (and hence a lower macroeconomic adjustment cost) reported in this paper, these would imply that Singapore's system would provide important insight on the choice of exchange rate system for many other small open economies.

even in the short run. This would in turn imply no role for exchange rate policy to help achieving internal balance in the small open economy. Thus, test and estimation results on the second and third goals will not only help Singapore check the appropriateness of its exchange rate policy, but are also important to the possibility of applying the practices in other small open economies.

Our fourth goal is to test whether higher productivity growth would result in a persistent rise in the real effective exchange rate [i.e., the Harrold-Balassa-Samuelson (HBS) effect as highlighted in Lothian and Taylor (2008)]. As shown in Figure 1 and Figure 3, both Singapore's REER and our measure of the productivity differential δ_t between Singapore and its 15 largest trading partners are moving in the upward direction during the sample period. Thus, in view of Lothian and Taylor's comment on previous empirical work, it would be useful to test whether their empirical finding of the HBS effect was also supported by the Singapore data. If so, future empirical studies on the mean reversion speed of real exchange rate and Purchasing Power Parity (PPP) should allow for the HBS effect, or at least test for such an effect before excluding it from the estimations or tests. Otherwise, as noted by Lothian and Taylor, this could result in biased estimates on the adjustment speed, as was probably the case in a significant portion of previous empirical work in this field.

It should be noted, whatever the empirical results are, the same underlying economic theories would imply the four test results in Singapore (i.e., the test results for linear or nonlinear adjustment of real exchange rate, HBS effect, long-run and short-run neutrality of exchange appreciations and depreciations) would also hold in many, though not necessarily all, other small open economies. Thus, the study is not only important to Singapore, but will also reflect quite a number of general characteristics of many other small open economies. The remaining part of this paper is summarized as follows. Section 2 is a brief literature review on why the STAR model should be used for the estimation and tests. Section 3 is a concise discussion of the econometric model and the data. The empirical results are reported in Section 4, and the implications of the results on Singapore's exchange rate policy are discussed in Section 5. Section 6 is the concluding section.

2. Nonlinear Adjustment of Real Exchange Rate: A Brief Review

Early empirical studies on the mean reversion speed of real exchange rate was based on a linear framework, i.e., they assumed a linear adjustment speed of real exchange rate towards the long run equilibrium (mostly, but not entirely, characterized by the PPP).[3] However, as summarized in the literature review by Taylor and Taylor (2004, p.146), these empirical studies have resulted in two important PPP puzzles that needed to be resolved. The first PPP puzzle is a "*puzzling lack of strong evidence for long run PPP*" in these early empirical studies. In particular, a "*large number of studies … have found that time-series deviations from PPP appear to be nonstationary …, implying the absence of any long-run tendency toward PPP*" (Taylor, Peel and Sarno, 2001, p.1016). The second PPP puzzle was pointed out by Rogoff (1996), who noted that the estimated speed of convergence to the long run equilibrium in the early empirical studies was extremely slow (i.e., deviations appeared to damp out at a rate of roughly 15% per annum, or with a half-life in the range of 3 to 5 years), and it would be hard to reconcile such a slow convergence speed with *"the enormous short-term volatility of real exchange rates*".

Taylor, Peel and Sarno (2001) believed one approach to resolve the two puzzles is to allow for nonlinear adjustment of real exchange rate towards the long run equilibrium. Based on the theoretical literature on transaction costs in international arbitrages, they explained that the convergence of real exchange rate to the long-run equilibrium should be nonlinear and could be modelled and estimated by the STAR regression. "*Using a version of a [STAR] model and just the post-Bretton Woods data …, they rejected the hypothesis of a unit root in favor of the alternative hypothesis of nonlinearly mean reverting real exchange rate, thus solving the [first] PPP puzzle*" (Taylor and Taylor, 2004, p.148). To strengthen their argument on the first PPP puzzle and the low power of standard unit root tests first conjectured by Frankel (1988, 1990),[4] they also used simulations to show that, *"when the real exchange rate is nonlinearly mean reverting, standard univariate unit root tests have low power*" for the case of shorter (15-year) time series data during the post-Bretton Woods period. Even for the

[3] See Froot and Rogoff (1995), Rogoff (1996), Taylor (1995) and Taylor and Taylor (2004) for a detailed survey on this early empirical literature.

[4] In response to the lack of empirical support for long-run PPP (or failure to reject the unit root tests) in the early empirical lecture, Frankel conjectured that these unit root tests were based on data covering 15 years or so since 1973, and therefore may have low power to reject the null hypothesis of a unit root even if it is indeed false (the conjecture was later supported by the simulation work mentioned in the main text). Frankel then run a regression with annual data of the dollar-sterling real exchange rate for a long time span between 1869 and 1984. He was able to reject the hypothesis of random walk at the 5% level, and therefore going some way to resolve the first PPP puzzle. Nevertheless, as noted in Rogoff (1996), Frankel's (linear) estimate would imply a glacial rate of adjustment of exchange rate of only 14% per annum, and therefore could not resolve the second PPP puzzle.

case of medium (30-year) time span due to availability of more post-Bretton Woods data, the increase in the power of the unit root tests was quite marginal (see also the simulation results by Taylor, 1997, and Sarno and Taylor, 2004).

Taylor, Peel and Sarno's nonlinear estimation also showed that the half-lives of real exchange rate shocks imply a faster adjustment speed of real exchange rate than previously recorded - thus going some way toward solving the second PPP puzzle.

One remaining problem of the above empirical studies is that they assumed the long-run equilibrium real exchange rate would remain constant over time. Lothian and Taylor (2008) noted that the assumption will, in the presence of the Harrold-Balassa-Samuelson (HBS) effect,[5] cause a biased estimate on the mean reversion speed of real exchange rate. They therefore explicitly modelled the HBS effect in the STAR model. In this paper, we will follow their work by assuming that Singapore's equilibrium real effective exchange rate (REER) could be affected by the productivity differential between Singapore and its 15 major trading partners. That is, by allowing a rising equilibrium REER due to the higher productivity growth in Singapore, we would be able to avoid the bias highlighted by Lothian and Taylor. Such a model will also allow us to estimate the impact of the productivity differential on Singapore's long run equilibrium real exchange rate (i.e., the HBS effect).

3. The STAR Model

To allow for nonlinear adjustment of real exchange rate and the HBS effect, we follow the literature by using the following STAR model:[6]

$$(q_t - \mu_t) = \sum_{i=1}^{k} \beta_{1i}(q_{t-i} - \mu_{t-i}) + \left[\sum_{i=1}^{k} \beta_{2i}(q_{t-i} - \mu_{t-i})\right] G(\gamma; q_{t-d} - \mu_{t-d}) + \varepsilon_t \quad (1)$$

where q_t is the demeaned series of the logarithm of the real effective exchange rate (REER) at period t; μ_t ($=\mu\delta_t$) is the logarithm of the long-run equilibrium of the REER which could now be affected by the demeaned series of the productivity differential δ_t between the economy and its 15 major trading partners; $q_t - \mu_t$ is the deviation of REER from its long run equilibrium; θ, β_{1i}, β_{2i} and γ are parameters; k is the autoregressive lag; d is the delay parameter; $\varepsilon_t \sim N(0, \sigma^2)$; $G(\gamma; y_{t-d} - \mu_{t-d})$ is the transition function

[5] The HBS effect was first identified and elaborated by Harrold (1933), Balassa (1964) and Samuelson (1964), and was therefore name as the Harrold-Balassa-Samuelson effect.

[6] For the econometric theories on STAR models and the related nonlinear unit root tests, see Granger and Teräsvirta (1993), Teräsvirta (1994, 1998), van Dijk, Teräsvirta and Franses (2002), Kapetanios, Shin and Snell (2003) and Sollis (2009).

which is usually specified in the form of exponential function (i.e., ESTAR model) or logistic function (i.e., LSTAR Model). Taylor, Peel and Sarno (2001) argued that, because the dynamic of real exchange rate is likely to be symmetric, the ESTAR model will usually be a better model for studies on the nonlinear adjustment of exchange rate. If so, the transition function in equation (1) could be written as:

$$G(\gamma; q_{t-d} - \mu_{t-d}) = 1 - \exp\left\{-\gamma(q_{t-d} - \mu_{t-d})^2\right\} \qquad \gamma \geq 0, d \geq 1 \tag{2}$$

Before the estimation, we will first select the appropriate specification by testing whether the LSTAR model or the ESTAR model will be a better model for the Singapore data.

Following the empirical literature, all the data series used in the estimation are the deseasonalized data. However, as we are evaluating the role of exchange rate policy in Singapore, our estimation will use the real effective exchange rate index (Q_t) instead of the bilateral exchange rates used in most studies in the literature. This would first involve the

(a) computation of Singapore's NEER index (S_t) against its top 15 trading partners;
(b) collection of Singapore's GDP deflator index as the domestic price index (P_t); and
(c) computation of the foreign price index (P_t^*) as the trade-weighted average of the GDP deflator index of Singapore's top 15 trading partners.

After that, q_t could be computed from the following identity: $q_t \equiv s_t + p_t - p_t^*$, where s_t, p_t and p_t^* are the demeaned series of the logarithm of S_t, P_t and P_t^*, respectively. Following Lothian and Taylor (2008), we assume that $\mu_t = \mu\delta_t$, where μ is the a parameter to be estimated, and δ_t is the demeaned series of "the domestic-foreign productivity differential", in which the home and foreign productivities are proxied by the logarithm of the real GDP per capita indices in Singapore and its 15 largest trading partners.

Before the formal estimation, we first plot Q_t and S_t in Figure 1, P_t and P_t^* in Figure 2, and δ_t in Figure 3 over the sample period between 1986Q1 and 2016Q4. As we can see, Singapore's nominal exchange rate S_t was appreciating over time, while Singapore's P_t was rising at a slower rate than P_t^* so that Singapore's real exchange rate Q_t ($\equiv S_tP_t/P_t^*$) was appreciating at a slower rate than S_t. That is, the appreciation of Singapore's NEER was associated with the lower inflation rate in Singapore, which was in turn accompanied by a REER appreciation slower than the NEER appreciation. Meanwhile, along with the rise in the Singapore-foreign productivity differential δ_t over time, there was also a rise in Singapore's REER.[7] In short, the plots of these figures provide some preliminary support for our discussion in Section 1, and our next step is to conduct rigorous tests on these hypotheses.

4. The Empirical Results

4.1 Preliminary tests

Our first step is to conduct both linear and nonlinear unit root tests on $y_t = q_t - \hat{\mu}_t$ [i.e., the deviation of real exchange rate q_t from the fitted long-run equilibrium $\hat{\mu}_t$].[8] As reported in Table 1, the ADF test and the PP test reject the null hypothesis of a linear unit root in the deviation of REER (y_t) at 5% significance level. In addition, the KSS test rejects the null hypotheses of a nonlinear unit root in the deviation of REER at 5% significance level. Thus, the test results satisfy the requirement of stationarity so that one is justified to conduct appropriate linear or nonlinear estimations on the (q_t–μ_t) equation.

Following the procedures recommended by Granger and Teräsvirta (1993) and Teräsvirta (1994, 1998), our next step is to use the AIC criterion to decide the optimal lag length k, use the LM statistic of the linearity test to decide whether a linear or nonlinear model should be used for the estimation (and decide the optimal delay parameter d in the case of a nonlinear model), and use the STAR-type test to decide whether the ESTAR model or LSTAR model should be used in the case that a nonlinear model is recommended by the previous LM test. As reported in Table 2, $k=5$ is the one with the lowest AIC (= –5.215) for the deviation of REER, we therefore set the optimal lag length k to be 5 for our estimation of the (q_t–μ_t) equation. Furthermore, as reported in Table 3, the LM statistic of the linearity test for the deviation of REER has the lowest P-value at $d=1$. As the P-value is only 0.006, the test rejects the null hypothesis of a

[7] To illustrate the effect of the productivity differential δ_t on the real exchange rate q_t, we also plot q_t and $\hat{\mu}\delta_t$ (i.e., the fitted long-run equilibrium of q_t) in Figure 4, where $\hat{\mu}$ is the estimate of μ obtained from the non-linear ESTAR estimation reported in Table 4.

[8] Together with the recommended procedures by Granger and Teräsvirta (1993) and Teräsvirta (1994, 1998), the series of procedures are as followed: (i) first run an ordinary least square estimation of q_t on δ_t; (ii) then use the residuals from the above regression for the preliminary tests and the selection of k and d. To double check the above procedures based on the ordinary least square estimation is a good approximation, we also use $\hat{\mu}$ (=0.186) in the nonlinear estimation reported in Table 4a to compute another series of y_t (= $q_t - \hat{\mu}\delta_t$), and use this series to repeat the recommended series of procedures. Again, the exercise give the same selected values of k and d, and qualitatively the same results in the linear and nonlinear unit root tests, the linearity test and the STAR-type test. Thus, our estimation result reported in Table 4a is not affected by whether the $\hat{\mu}$ is obtained from the ordinary least square estimation or the formal STAR estimation reported in Table 4a.

linear model at 1% significance level, and suggests a nonlinear model with $d = 1$. Finally, the F_2 statistic for the deviation of REER in the STAR-type test reported in Table 3 has the lowest P-value (=0.008) when compared with the corresponding values of the F_1 and F_3 statistics, thus suggesting that the ESTAR model should be used for the nonlinear estimation of our ($q_t - \mu_t$) equation.

4.2 The estimation results

In Section 1, we have noted that Singapore's exchange rate policy could result in (i) nonlinear STAR adjustment of Singapore's REER to the long-run equilibrium; and (ii) a faster adjustment speed in Singapore's REER when compared with many other economies. Let us check whether the estimation result supports the argument. As shown in Table 4a,[9] the estimate of the ESTAR parameter γ is of the right sign and significant at 5% level. The significance of the ESTAR parameter γ further confirms our LM test result that a nonlinear model instead of a linear model should be used for the estimation. That is, there is evidence that the adjustment of Singapore's REER to the long run equilibrium is nonlinear. With exchange rate policy being used to facilitate macroeconomic adjustment, the magnitude of the estimate of γ (= 7.604) is also larger than the estimates for other economies reported in Lothian and Taylor (2008) and Taylor, Peel and Sarno (2001).[10] Thus, the estimation result suggests that the adjustment of real exchange rate is relatively fast in Singapore. Such a result is consistent with Section 1's conjecture that exchange rate policy in Singapore plays an important role in facilitating the adjustment of real exchange rate in the small open economy.

To support our subsequent comparison exercise with linear models, we also conduct a half-life analysis by calculating the impulse response functions to various sizes of shocks in q_t conditional on average initial history. As reported in Table 4b, for

[9] As shown in the lower panel of the table, all the misspecification tests on serial correlation and heteroskedasticity were passed: The P-values of the LM test for serial correlation [i.e., AR(1) and AR(4)] are 0.615 and 0.952, which suggest that one cannot reject the null hypotheses of no first order and fourth order serial correlation in the residuals. The P-value of the first order autoregressive heteroskedasticity LM statistic [i.e., ARCH(1)] is 0.907, thus implying no evidence against the null hypothesis of no first order heteroskedasticity in the residuals.

[10] The size of our estimate of γ (=7.604) is much bigger than the estimate of 3.023-3.218 reported in Lothian and Taylor (2008) and the estimate of 0.170-0.452 reported in Taylor, Peel and Sarno (2001). It should also be noted that for ESTAR models, (i) the size of the estimated γ is independent of the frequency of the data; and (ii) the difference in the values of the estimated γ (instead of the difference in the lengths of the half-life) would better reflect the difference in the adjustment speeds of the adjusting variable.

medium-size shocks such as a 5% or 10% shock in q_t, the half-life is about 7 quarters. On the other hand, for large shocks such as a 20% or 30% shock in q_t, the half-life declines substantially to about 3 quarters.

To investigate whether the argument on the PPP puzzle by Taylor, Peel and Sarno (2001) also applies to the case of Singapore, we also report the linear estimation result in Table 5 and compare it with the nonlinear estimation result in Tables 4a-b. As reported in Table 5, the linear model would imply a very slow mean reversion speed of real exchange rate to the long run equilibrium: For examples, the implied half-life for any size of shock would be 16 quarters,[11] which is similar to that of the linear models reported in the early literature (e.g., about 3 to 5 years as noted in Rogoff, 1996) but much longer than the 3-7 quarters for the nonlinear model reported in Table 4b. Thus, the comparison of our linear and nonlinear estimation provides an additional support for the argument by Taylor, Peel and Sarno (2001): The use of the linear model in the early empirical work on PPP could be one of the underlying reasons for the second PPP puzzle, and one promising way to solve the puzzle is to allow for nonlinear adjustment in the real exchange rate.

On the question of the HBS effect, Table 4a shows that the estimate of μ (=0.186) is of the right sign and significant at 1% level. Thus, there is evidence for the existence of the HBS effect in Singapore. The HBS effect could also be visualized with the plot of q_t and $\hat{\mu}\delta_t$ in Figure 4: the real exchange rate q_t is moving around the fitted long-run equilibrium path ($\hat{\mu}\delta_t$) instead of a horizontal line. To demonstrate the importance of including the HBS effect in our estimation, we repeat the estimation of the real exchange rate equation without including the HBS effect as the determinant of the long run equilibrium REER. The result is reported in Table 6. As we can see from the table, the estimate of the ESTAR parameter γ (=14.802) is much higher than that reported in Table 4a. Given that our estimate of the HBS effect in Table 4a is significant, the difference in the estimation results is consistent with Lothian and Taylor's argument. That is, our estimation exercises provide an additional support for Lothian and Taylor's argument that failure to include the HBS effect in the estimation could result in a biased estimate of the adjustment speed of real exchange rate. Thus, one should be cautious of the significant portion of past empirical studies which did not

[11] As the linear model assume a linear adjustment speed in the real exchange rate, the half-lives for any size of shock will be the same.

incorporate the HBS effect in their estimations or tests. It also implies future empirical studies should incorporate the effect in their estimations and tests, or at least test for the absence of the effect before excluding it from the estimations and tests.

Finally, to check that the relatively fast adjustment of Singapore's REER reported in Table 4a was not due to a fast adjustment of domestic price and to test for the long-run neutrality and short-run non-neutrality of Singapore's exchange rate policy, we repeat the same test and estimation procedures for Singapore's deviation of domestic price. That is, we first conduct the preliminary tests (i.e., the linear and nonlinear unit root tests, the linearity test and the STAR-type test)[12] for the deviation of domestic price from the long-run equilibrium, which suggest that there is also a nonlinear adjustment in domestic price and the following ESTAR model with $\tilde{k} = 3$ and $\tilde{d} = 2$ should be used for the estimation:

$$(p_t - \tilde{\mu}_t) = \sum_{i=1}^{\tilde{k}} \tilde{\beta}_{1i}(p_{t-i} - \tilde{\mu}_{t-i}) + \left[\sum_{i=1}^{\tilde{k}} \tilde{\beta}_{2i}(p_{t-i} - \tilde{\mu}_{t-i})\right]\left\{1 - \exp\left[-\tilde{\gamma}(p_{t-d} - \tilde{\mu}_{t-d})^2\right]\right\} + \tilde{\varepsilon}_t \quad (3)$$

with $$\tilde{\mu}_t = \tilde{\phi}(p_t^* - s_t) + \tilde{\mu}\delta_t \quad (4)$$

where p_t is the demeaned series of the logarithm of domestic price at period t so that $(p_t - \tilde{\mu}_t)$ is the deviation of domestic price (p_t) from its long-run equilibrium ($\tilde{\mu}_t$); the long run equilibrium of domestic price ($\tilde{\mu}_t$) is an increasing function of foreign price expressed in domestic currency $(p_t^* - s_t)$ and the productivity differential (δ_t); $\tilde{\beta}_{1i}$, $\tilde{\beta}_{2i}$, $\tilde{\gamma}$, $\tilde{\mu}$ and $\tilde{\phi}$ are parameters, $\tilde{k}$ is the autoregressive lag, $\tilde{d}$ is the delay parameter; and $\tilde{\varepsilon}_t \sim N(0, \tilde{\sigma}^2)$.

The estimation result is reported in Table 7. Of particular interest is the estimate of $\tilde{\phi}$ (=0.995) is very close to 1. That is, 1 percentage point rise (reduction) in foreign price (P_t^*) or 1 percentage point depreciation (appreciation) in Singapore's NEER (S_t)

[12] As reported Table 1, the ADF test and the PP test reject the null hypothesis of a linear unit root in the deviation of domestic price at 5% and 1% significance level, respectively. The KSS test also rejects the null hypothesis of a nonlinear unit root in the deviation of domestic price at 1% significance level. Thus, the test results satisfy the requirement of stationarity so that one is justified to conduct appropriate linear or nonlinear estimation of the $(p_t - \tilde{\mu}_t)$ equation. Furthermore, as reported in Table 2, $\tilde{k}=3$ is the one with the lowest AIC for the deviation of domestic price. We therefore fix $\tilde{k}=3$. In Table 3, the linearity test for the deviation of domestic price has the lowest P-value of 0.007 at $\tilde{d}=2$, thus rejecting the null hypothesis of a linear model and suggesting that we should use a nonlinear model with $\tilde{d}=2$. Finally, the F_2 statistic for the deviation of domestic price in the STAR-type test has the lowest P-value (=0.006) when compared with the corresponding values of the F_1 and F_3 statistics, thus suggesting that the ESTAR model should be used for the nonlinear estimation of the domestic price equation.

would cause about 1 percentage point rise (reduction) in domestic price in the long run. To test for the long-run neutrality result, we conduct a formal Wald test on the null hypothesis of $\tilde{\phi} = 1$. As the P-value of the test statistic is 0.922, we cannot reject the null hypothesis of $\tilde{\phi} = 1$ at 10% level. This result is important as it would mean that exchange rate policy in Singapore would be neutral in the long run, i.e., any appreciation (depreciation) in Singapore's NEER will eventually cause a proportionate decline (rise) in domestic price relative to the foreign price.

Meanwhile, the estimated value of $\tilde{\gamma}$ is 2.798, which is much smaller than the corresponding estimate of 7.604 for the deviation of REER. This suggests that the adjustment in price is relatively sluggish, and changes in NEER beyond the anticipated appreciation path would be non-neutral in the short run. We will come back to the policy implications of the long-run neutrality and short-run non-neutrality results in Section 5.

5. Further Discussion on Singapore's Exchange Rate Policy

In Section 4, we have found evidence for the long-run neutrality and short-run non-neutrality of the exchange rate policy in Singapore. According to equation (4) and the null hypothesis of $\tilde{\phi} = 1$, the long-run neutrality result would imply that any NEER appreciation (depreciation) in Singapore would, after appropriate deduction of the REER appreciation due to the productivity growth differential, cause a proportionately lower (higher) domestic inflation without any effect on the relatively price competitiveness and output in Singapore. Given that the estimated effect of the productivity growth differential was 0.54% per annum during the sample period, this would imply Singapore's policy of an average NEER appreciation of 1.51% per annum over the sample period would mean that the domestic inflation would be lower than the foreign inflation by 0.97%. A cross check of the inflation data over the past three decades between 1986Q1 and 2016Q4 (i.e., the sample period) confirms the long-run neutrality hypothesis: the average domestic inflation (1.37% per annum) was lower than the average foreign inflation (2.34% per annum) by 0.97% per annum, thus confirming the belief that the gradual NEER appreciation over the past three decades have been fully incorporated in the price and wage decisions in Singapore.

In other words, the long-run benefit of Singapore's gradual appreciation over the past three decades is a lower domestic inflation without any direct long-run benefit or cost in its relative price competitiveness and output. The latter result also explains why Singapore's development strategy over the past few decades is to increase its production capacity (i.e., shifting the full employment output line out) through strategies such as investment in capital and technology, industrial upgrading and development of high value-added industries, attracting high-technology and high value-added foreign direct investments, attracting foreign skilled labor and upgrading domestic labor force.

Our estimation result also confirms that Singapore could use permanent change in real exchange rate to facilitate macroeconomic adjustment to permanent shocks. For example, in case of a moderate positive (negative) permanent shock in productivity growth, the Singapore monetary authority could adopt faster (slower) appreciation until the REER rises (falls) to the new long-run equilibrium. In the extreme case of a severe negative permanent shock, Singapore could even allow or engineer a substantial depreciation to facilitate the adjustment of the REER instead of waiting for the sluggish price adjustment to achieve the macroeconomic adjustment.

Meanwhile, the short-run non-neutrality (or price sluggishness) result would imply that Singapore could, and should, use exchange rate policy to facilitate macroeconomic adjustment to cyclical shocks: For example, consider the case of a long-run equilibrium scenario in which Singapore's NEER is appreciating at 1.5% per annum, which is fully anticipated and priced in the wage and price decisions in Singapore so that domestic price is rising at a rate as suggested by equation (4), i.e., domestic price will rise at a slower rate than foreign price by the difference between the NEER appreciation rate and the effect of the productivity growth differential. Now suppose the Singapore monetary authority anticipates a negative external shock that might soon cause a mild recession in Singapore. Singapore could announce a return to the stable Singapore dollar stance (i.e., Singapore NEER will remain stable) until the next decision meeting. Such a shift from the usual 1.5% appreciation stance to zero appreciation stance would temporarily improve Singapore's relative price competitiveness by 1.5% per annum, which would in turn help offset the effect of the anticipated negative cyclical shock. In the event of a very big negative shock, such as that during the post-crisis recession in the aftermath of the 1997-98 Asian financial crisis, the Singapore monetary authority had adopted the extraordinary policy of allowing and encouraging an 8.5% depreciation of Singapore's NEER between 1998Q1 and 1999Q1. Together with a significant cut in the wage cost through a temporary reduction of the employer's CPF contribution rate by 10 percentage point and some fiscal relieve programs until the end of the post-crisis recession, this had substantially reduced the subsequent recession in Singapore (see Yip, 2005 for the detailed discussion).

On the other hand, if there is a positive shock that causes an overheating or a higher inflation in Singapore, the Singapore monetary authority could engineer a higher appreciation rate to, say, 4% or 5%. Thus, the 2.5% or 3.5% gap between the actual and expected appreciation would help to reduce domestic inflation directly through a reduction in imported inflation[13] and indirectly through a reduction in net export (and hence aggregate demand) in Singapore.

6. Conclusions

In this paper, we have used the nonlinear unit root test, the linearity test and the STAR-type test to show that adjustment of Singapore's real exchange rate to the long-run equilibrium is nonlinear, and should be modelled and estimated by an ESTAR model. Our estimation result shows that the implied adjustment speed of real exchange rate is much faster than the linear estimates reported in the early empirical literature. Thus, the above tests and estimation results provide a further support for the argument by Taylor, Peel and Sarno (2001) and Lothian and Taylor (2008) that the move to nonlinear adjustment model of real exchange rate would be a promising approach to resolve the first and second PPP puzzles.

Unlike the economies studied by Taylor, Peel and Sarno (2001) and Lothian and Taylor (2008), the economy selected in this paper (i.e., Singapore) has been using exchange rate policy to facilitate adjustment of real exchange rate over the past three decades. Thus, it is not surprising that the estimated adjustment speed reported in this paper is also faster than that reported by them. In fact, we see the difference in the adjustment speed as an evidence for the hypothesis that exchange rate policy to facilitate macroeconomic adjustment would lead to a nonlinear adjustment of real exchange rate, and a STAR model should be used for the estimation. The latter is further supported by the difference in the estimation results between the non-linear model (Tables 4a-b) and the linear model (Table 5),

[13] As a small open economy in which a significant portion of consumption, investment and government expenditure are imported, the impact through the reduction of imported inflation would be quite significant.

Our estimation result also shows that there is strong evidence for the HBS effect in Singapore. Comparing the result in Table 4a with the case of no HBS effect in Table 7 also provides an additional support for the following argument by Lothian and Taylor (2008): Failure to incorporate the HBS effect in the estimation could lead to biased estimates of the adjustment speed of real exchange rate. Pushing the argument a bit further, this would mean that one should be cautious of the significant portion of past empirical studies that did not include the HBS effect in their estimations. Future empirical studies should include the effect in the estimations and tests, or at least test for the absence of the effect before excluding it from the estimations.

Finally, we also found evidence for the long-run neutrality and short-run non-neutrality in Singapore's exchange rate policy. This provides a strong empirical support for the following theoretical arguments and practices in Singapore's exchange rate policy: Singapore's average NEER appreciation over the past three decades has already been fully incorporated in the wage and price decisions in Singapore. This has in turn contributed to a lower domestic inflation without any loss in its relative price competitiveness. On the other hand, the short-run non-neutrality result implies that Singapore could still use the exchange rate policy to reduce the macroeconomic adjustment cost when there is a permanent shock or cyclical shock that necessitates an adjustment in the real exchange rate. With the faster estimated adjustment speed of real exchange rate, Singapore's ability to use the exchange rate policy in facilitating macroeconomic adjustment and controlling inflation, and the other successes highlighted in the literature on Singapore's exchange rate policy (see the literature mentioned in footnote 2), more serious attention on the economic system and practices in Singapore could give important insight on the choice of exchange rate system in many other small open economies.

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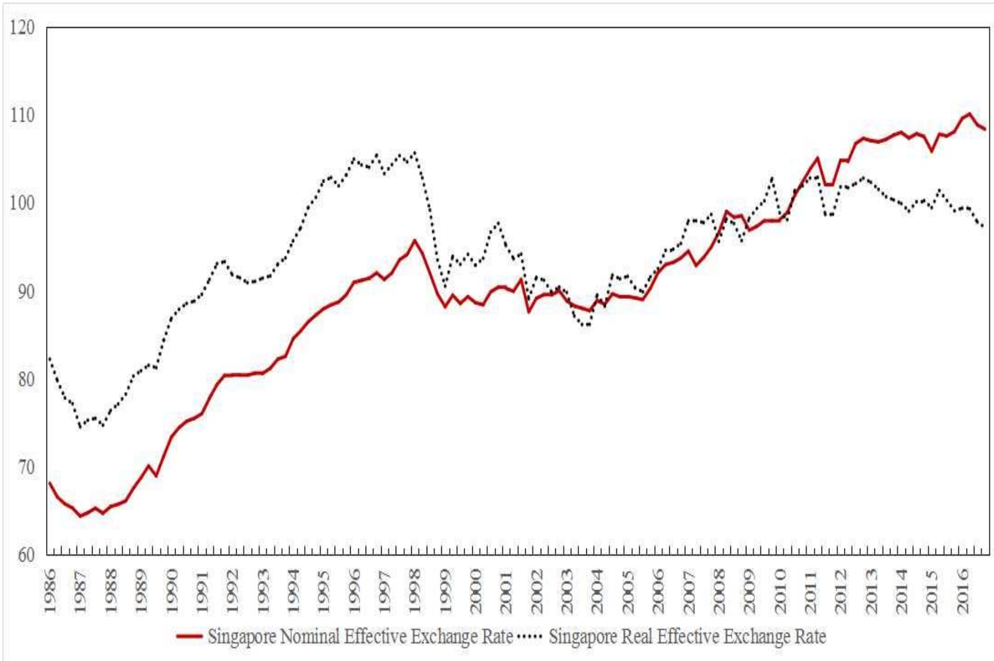

Fig. 1: Singapore's NEER Index and REER Index

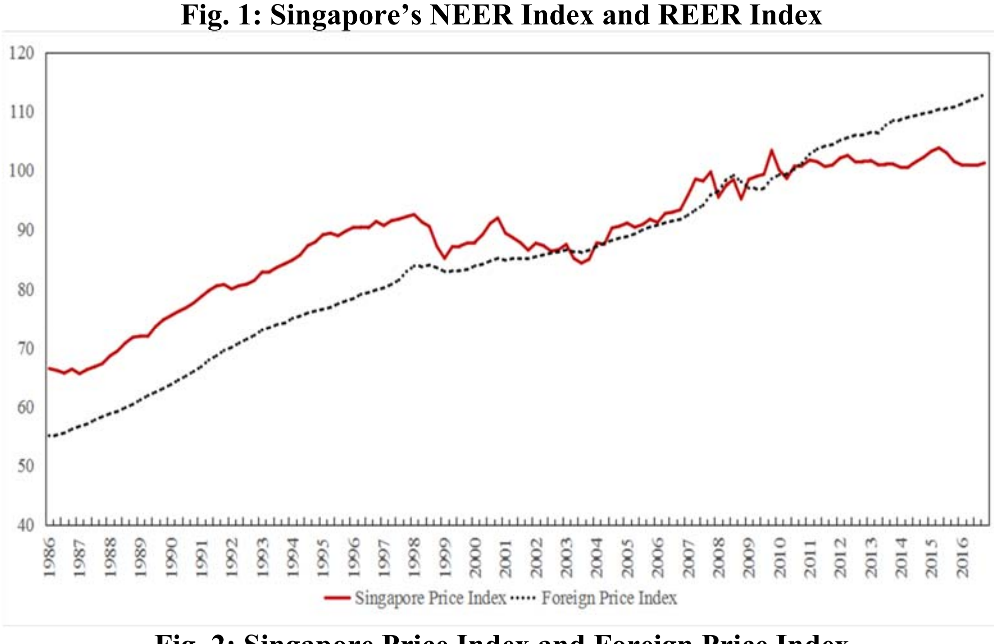

Fig. 2: Singapore Price Index and Foreign Price Index

Fig. 3. The Domestic-foreign Productivity Differential for Singapore

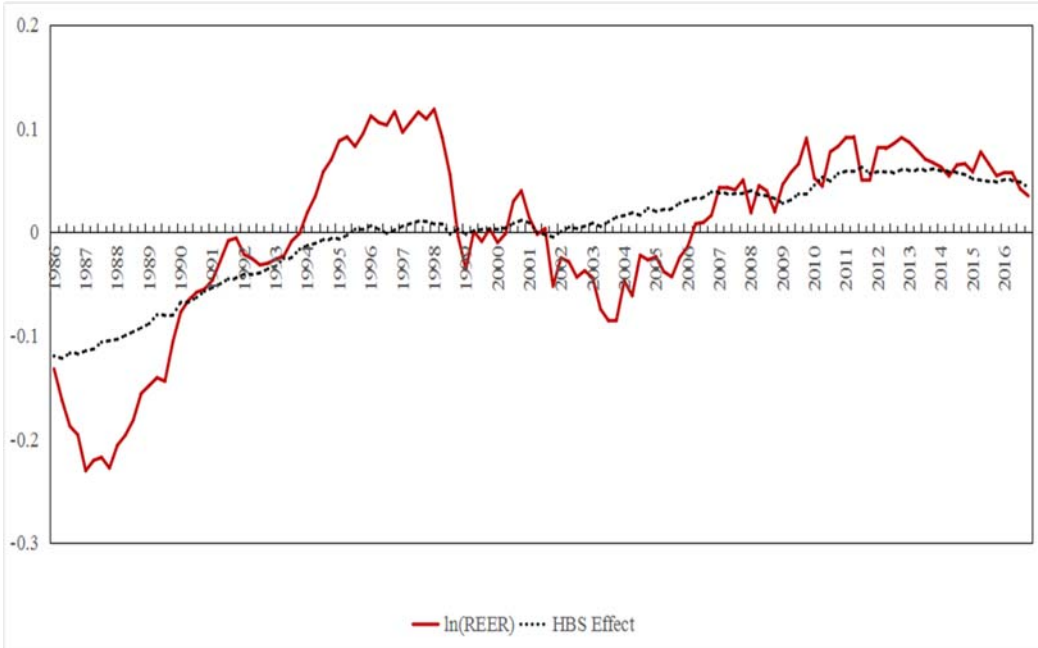

Fig. 4. Singapore REER and the fitted Long Run Path with the HBS Effect

Table 1: Results for the Linear and Nonlinear Stationarity Tests

	Linear Unit Root Test		Nonlinear Unit Root Test
	ADF	PP	t_{KSS}
Deviation of REER	-2.150[0.031]**	-2.169[0.030]**	-3.401[0.046]**
Deviation of Price	-3.401[0.013]**	-3.372[0.001]***	-3.988[0.007]***

Notes: The 1%，5%，10% critical values for the KSS test (2003) statistics are -3.48, -2.93, -2.66, respectively. Superscripts ***, ** and * ,respectively, denotes significance at 1%, 5% and 10% levels.

Table 2: Result for the AIC Tests

k	1	2	3	4	5	6	7	8	9	10
Deviation of REER	-5.164	-5.154	-5.158	-5.169	-5.215$^{\#}$	-5.199	-5.210	-5.186	-5.169	-5.143
Deviation of Price	-3.855	-3.853	-3.917$^{\#}$	-3.907	-3.905	-3.885	-3.860	-3.913	-3.897	-3.872

Notes: $^{\#}$ denotes the optimal lag length.

Table 3. P-values of the Linearity Tests and STAR-type Tests

	Linearity test							STAR-type test		
	1	2	3	4	5	6	7	$P(F_1)$	$P(F_2)$	$P(F_3)$
Deviation of REER(k=5)	0.006$^{\#}$	0.029	0.123	0.624	0.457	0.529	0.155	0.055	0.008$^{\#}$	0.095
Deviation of Price(k=3)	0.094	0.007$^{\#}$	0.196	0.518	0.486	0.505	0.193	0.061	0.006$^{\#}$	0.089

Notes: $^{\#}$ denotes the optimal delay parameter and the optimal model type.

Table 4a: ESTAR Estimation Result for the Deviation of REER

Parameter	Coefficient	t-statistics	Probability
γ	7.604	2.724	0.015
β_{12}	-0.437	-1.801	0.072
β_{13}	0.564	2.505	0.012
β_{22}	0.519	1.749	0.080
β_{23}	-0.768	-2.580	0.010
μ	0.186	3.602	0.000
R^2	0.903		
$AR[1]$	0.252[0.615]		
$AR[4]$	0.691[0.952]		
$ARCH[1]$	0.014 [0.907]		

Notes: Figures in square brackets denote the P-values of the estimated statistics. $\overline{R}^2$ is the adjusted coefficient of determination AR[1] and AR[4] are the Largrange Multiplier (LM) statistics for first-order and fourth-order serial correlation of residuals. ARCH[1] is the Largrange Multiplier (LM) statistic for first-order autoregressive heteroscedasticity of residuals. In the estimated ESTAR model, we only report the significant AR parameters.

Table 4b: Estimated Half-Lives for shocks in q_t

Shock in q_t (%)	30	25	20	15	10	5
Half-life (quarters)	3	3	3	7	7	7

Notes: Half-lives of the real exchange rate shocks were calculated by Bootstrap methods based on the model estimates reported in Table 4a. The impulse response functions were calculated conditional on average initial history.

Table 5: Linear Estimation Result for the Deviation of REER

Parameter	Coefficient	t-statistics	Probability
β_1	0.909	10.054	0.000
β_2	0.047	0.394	0.694
β_3	0.119	0.999	0.320
β_4	-0.322	-2.703	0.008
β_5	0.182	2.061	0.042
R^2	0.880		
$AR[1]$	0.758 [0.384]		
$AR[4]$	4.513 [0.341]		
$ARCH[1]$	0.102[0.749]		
Half-life	16 quarters		

Notes: Figures in square brackets denote the P-values of the estimated statistics. $\overline{R}^2$ is the adjusted coefficient of determination AR[1] and AR[4] are the Largrange Multiplier (LM) statistics for first-order and fourth-order serial correlation of residuals. ARCH[1] is the Largrange Multiplier (LM) statistic for first-order autoregressive heteroscedasticity of residuals.

Table 6: ESTAR Estimation Result for Deviation of REER without HBS Effect

Parameter	Coefficient	t-statistics	Probability
γ	14.802	1.885	0.059
β_{11}	1.779	2.753	0.006
β_{16}	-1.266	-2.711	0.007
β_{17}	0.878	2.338	0.019
β_{26}	1.451	3.012	0.003
β_{27}	-1.200	-3.158	0.002
μ_0	0.005	1.681	0.093
R^2	0.902		
$AR[1]$	0.144 [0.704]		
$AR[4]$	1.241 [0.871]		
$ARCH[1]$	0.085 [0.771]		

Notes: Figures in square brackets denote the P-values of the estimated statistics. $\overline{R}^2$ is the adjusted coefficient of determination AR[1] and AR[4] are the Largrange Multiplier (LM) statistics for first-order and fourth-order serial correlation of residuals. ARCH[1] is the Largrange Multiplier (LM) statistic for first-order autoregressive heteroscedasticity of residuals. In the estimated ESTAR model, we only report the significant AR parameters.

Table 7: ESTAR Estimation Result for the Deviation of Price

Parameter	Coefficient	t-statistics	Probability
$\tilde{\gamma}$	2.798	2.980	0.003
$\tilde{\phi}$	0.995	6.145	0.000
$\tilde{\beta}_{11}$	0.620	3.890	0.000
$\tilde{\beta}_{13}$	0.337	2.421	0.015
$\tilde{\beta}_{21}$	0.510	2.421	0.015
$\tilde{\beta}_{23}$	-0.773	-3.653	0.000
$\tilde{\mu}$	1.709	2.870	0.004
$\overline{R}^2$	0.910		
$AR[1]$	0.063 [0.802]		
$AR[4]$	5.988 [0.200]		
$ARCH[1]$	1.161 [0.281]		
Wald-test for $\tilde{\phi} = 1$	-0.374 [0.922]		

Notes: Figures in square brackets denote the P-values of the estimated statistics. $\overline{R}^2$ is the adjusted coefficient of determination AR[1] and AR[4] are the Largrange Multiplier (LM) statistics for first-order and fourth-order serial correlation of residuals. ARCH[1] is the Largrange Multiplier (LM) statistic for first-order autoregressive heteroscedasticity of residuals. In the estimated ESTAR model, we only report the significant lags of AR parameters.