Econ.842 Term Paper
The Exchange Rate in China

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Abstract

The smooth threshold autoregressive (STAR) model is by far the most successful model in explaining the well-known two PPP puzzles. The nonlinearity in STAR captures the nature of vast transaction costs in trade, sunk costs in (foreign) investment, and hetergeneity in agents. In this paper, we use a variant of STAR, the Exponential STAR (ESTAR), to study the exchange rate dynamics in China during 1979∼2006. First, we use a general equilibrium model that considers both internal and external balances to estimate the equilibrium exchange rate. Then, we identify that the best ESTAR for China's exchange rate should be one time lag and one time delay model. Given the estimated parameters from nonlinear least square, simulation suggests that the half-life of 50% shock is slightly more than 2 years. Roughly speaking, a deviation of 10% or more from equilibrium level will be facing heavy arbitrage pressure.

Keywords: equilibrium exchange rate, PPP
JEL Classification: F31, F37

1 Introduction

Purchasing Power Parity (PPP) states that the price of a basket of identical goods (that is, identical quality and weights) in any two countries, if expressed in terms of a common currency, should be the same. In other words, the exchange rate (indirect pricing) in equilibrium, similar to the "Gold Standard", should be the ratio purchasing power (gold content) of two currencies. PPP was formally introduced almost a century ago (Cassel, 1918).

However, PPP bases on the very strong (unrealistic) assumption that goods of any two countries are all tradable and can be frictionlessly traded. That is to say, the rationale of PPP depends on perfect arbitrage. In reality, a vast of non-tradable goods, all kinds of trade and non-trade barriers, shipping time, etc., all make the arbitrage, to a large extent, imperfect. Therefore, empirical evidences of real exchange, especially in the short run, largely betray PPP. Nevertheless, the intuitive appeal still makes many economists believe that some variant of PPP can still serve as a good anchor for long-run real exchange rates (Dornbusch and Krugman, 1976; Rogoff, 1996).

Yet it is still under lively debate for whether or not PPP holds even in the long-run. Early studies such as Roll (1979) and Adler and Lehmann (1983) showed that real exchange rates follow a random walk. In the late 1980s, Engle and Granger's (1987) and many following studies showed that real exchange rates follow a unit root process. But as pointed out by Frankel (1986 and 1990), the failure of rejecting unit root is probably due to limit observations of real change rates. If enlarge the size of samples, the maintained hypothesis of unit root can be rejected. For example, Frankel (1986) rejected the unit root hypothesis using the real exchange rate between U.S. dollar and British Sterling during 1869-1984 and Abuaf and Jorion (1990) also reported rejection by using the panel data of multiple real exchange rates. Unfortunately, both long span approach and panel data approach seem problematic. The long span data approach does not take into account of the possible regime changes during such a long sample period whilst the panel data approach could overconfidently reject the unit root hypothesis even if there were only one real exchange rate in the panel that does not have a unit root.

In any event, advocates of PPP that use traditional linear approach can not answer the following two phenomenon, or "two puzzles", in real exchange rates (Taylor, Peel, and Sarno, 2001). The first puzzle is why the real exchange rates are so volatile as their nominal ones which seems not to converge to some level suggested by PPP. The second puzzle is why the implied speed of mean-reversion of the real exchange rate seems so slow even if PPP does hold in the long-run?

The surge of nonlinear dynamic PPP approaches that starts from late 1980s seems to be convincing ways to resolve these two puzzles. (Taylor and Taylor, 2004) This line of models is motivated by the frictions in the goods markets and asset markets. That is, there are various transaction costs (such as tariff, shipment cost, shipping time, etc.) and sunk costs that make arbitrage imperfect. Therefore, even if there does exist an equilibrium real exchange rate suggested by PPP, there must be a "band of inaction" within which arbitrage does not occur even though the real exchange rate deviates from its equilibrium level. This kind of model is known as "threshold autoregressive" (TAR). Then the first puzzle can be explained as a real exchange rate follows a random walk because it is in the inactive band. TAR has been widely applied in empirical studies and proved to have good fit for the data. (For example, Prakash and Taylor, 1996; Obstfeld and Taylor, 1997; Sarno, Taylor, and Chowdhury, 2004) Furthermore, based on the assumption of heterogeneous agents, Granger and Teräsvirta (1993) extended TAR to a so-called "smooth-transition autoregressive" (STAR) model. Intuitively, agents are heterogeneous in terms of the information sets and decision-making rules on exchange rates, thus agents have different views on "band of inaction". However, if the deviation of the exchange rate is too far, most agents will act in the same direction, thus the deviation shrinks fast. Therefore, there is no sudden or discrete change of deviation adjustment, it is rather continuous. Furthermore, the speed of adjustment is slower when deviation is smaller and faster when deviation is enlarged. This idea is supported by the "lazy S" shape of the adjustment process of actual exchange rate dynamics as documented in Taylor and Taylor (2004). Thus, STAR seems to be a good approach that can resolve both puzzles.

By far, there have been few studies on exchange rate in China. It is probably due to Chinese government's rigorous controls on its nominal exchange rate and asset market. Such controls make arbitrage largely imperfect and thus generate a very broad band of inaction. As a result, the "equilibrium" real exchange rate in China varies a lot in different studies. (For example, Chou and Shih, 1998; Chen, 1999; Yang and Dou, 2004; Ren and Ning, 2004). However, the fact that recently China has been rapidly accumulating U.S. bonds apparently reveals that China's exchange rate has deviated from its equilibrium so much that it has already exceeded the boundary of inactive band and thus China is forced to sterilize its exchange rate a lot. The cost of sterilization is that China, as the biggest developing country in the world which is thirsty of investment, is forced to be the biggest investor in U.S. public sectors!

As the sterilization cost is skyrocketing and China has promised to free its asset market to the rest of the world, it is urgent for China to adjust (if it so desires) its exchange rate within a "safety" band where big arbitrage is unlike to occur. Given the great success of STAR in interpreting the dynamics of real exchange rates, we use a variant of STAR to study China's exchange rate and try to find the reasonable rate as well as the safety band so that China can avoid possible financial and economic crisis (such as the Southeast Asia crisis in 1997) caused by misvalued currency.

The rest of the paper is organized as follows. Section 2 outlines the model for equilibrium exchange rate and the selected STAR model. Data and estimation are described in section 3. Section concludes.

2 The Equilibrium Exchange Rate Model and STAR

2.1 The Determination of Equilibrium Exchange Rate

There are two major types theories on the determination of equilibrium exchange rate. The well-known PPP theory is based on arbitrage whilst there also exists theories that are based on the internal and external balance. Examples of such theories include, but not limited to, the fundamental equilibrium exchange rate mechanism (Williamson, 1983), the natural real exchange rate approach (Stein, 1994), the behavioral equilibrium exchange rate approach (Clark and MacDonald, 1999), and the Equilibrium Exchange Rates theory (Edwards, 1989).

On the one hand, though PPP is straightforward, it ignores the fact that a large fraction of goods are non-tradable. So PPP that relies on general prices of both tradeables and non-tradables has its intrinsic flaws as shown by the well-known Balassa-Samuelson effect. On the other hand, theories that base on general equilibrium are theoretically sound, but the mechanism is much more complicated than PPP and thus increases the difficulty in empirical applications. Therefore, we view an ideal empirical model for equilibrium exchange rate should better reconcile PPP with the general equilibrium approaches, that is, a PPP model which builds on the microfoundation of general equilibrium. In this paper, we borrow Cuong Le Van, Ceeile Couharde, and Thai Bao Luong's (2006) general equilibrium model of the equilibrium exchange rate with small modification. In the following, we outline the model.

Consider a small open economy with two production sectors, tradable sector "T" and non-tradable sector "N". Labor, l, is freely mobile within a country but immobile between countries and it is normalized to be unity. The wage, w, is equalized in both sectors within a country. Capital, k, can be frictionlessly mobile both domestically and internationally and it is also normalized to be unity. r denotes The interest rate. Productivity in tradable sector and non-tradable sector are given by A_T and A_N respectively. The international goods market is frictionless so that arbitrage is perfect and PPP holds.

Production function is Cobb-Douglus: $y_i = A_i l_i^\alpha k_i^\beta$ $(i = 1, 2)$. The producers problem is given by, $\underset{l_i,k_i}{Max} \{P_i y_i - w l_i - r k_i\}$; the consumer's problem is given by, $\underset{C_T,C_N}{Max} \{\ln C_T + \zeta \ln C_N\}$ subject to.$P_T C_T + P_N C_N + P_T M = P_T y_T + P_N y_N + P_T X$, where C_T and C_N are consumptions on tradable goods (including import) and non-tradable goods respectively. M denotes imports and X denotes exports. Furthermore, the internal balance requires $C_T + X = y_T + M$ and $C_N = y_N$; and the external balance requires $P_T(M - X) = \lambda(P_T y_T + P_N y_N)$, where λ is the (foreign) debt-to GDP ratio.

Therefore, the equilibrium price level can be derived as,

$$\ln P = \ln r - \ln \beta + (1-\alpha-\beta)[\theta \ln \theta + (1-\theta)\ln(1-\theta)] - \theta \ln A_T - (1-\theta)\ln A_N \tag{1}$$

where $\theta = \frac{P_T y_T}{P_T y_T + P_N y_N} = \frac{1-\zeta\lambda}{1+\zeta}$ denotes the share of tradable goods in GDP.

Thus a relative PPP can be expressed as,

$$\overset{\bullet}{U} = \overset{\bullet}{P} - \overset{\bullet}{P}^* \tag{2}$$

where $\overset{\bullet}{X} = \frac{dX}{X}$ denotes the rate of change and U is the equilibrium exchange rate .

If the term $(1-\alpha-\beta)[\theta \ln \theta + (1-\theta)\ln(1-\theta)]$ is constant (i.e. in the short-run or medium-run), then equation (2) can be rewritten as,

$$\overset{\bullet}{U} = (\overset{\bullet}{r} - \overset{\bullet}{r}^*) - (\overset{\bullet}{A} - \overset{\bullet}{A}^*) \tag{3}$$

where $A = \theta \ln A_T + (1-\theta)\ln A_N$ is the total factor productivity (TFP). (3) is our empirical model of the equilibrium (nominal) exchange rate. It implies that the equilibrium exchange rate is determined by differential of the differentials of changes in interest rates and TFP.

2.2 The Exchange Rate with Transaction Cost: The STAR Model

According to Taylor and Taylor (2004), STAR is so far the best line of models which has both sound theoretical foundation and good fit for empirical dynamics of exchange rates. The threshold of deviation of an exchange rate from its equilibrium level is determined by various trade costs and sunk costs in (foreign) investment. (For example, Dixit, 1989; Krugman, 1989, Dumas, 1992). Within the threshold, there is an inactive band where arbitrage can not occur. Therefore, the deviation in the band should be a random walk as suggested by the short-run data. If the exchange rates deviate outside of the threshold, then arbitrage makes it revert towards its mean (the equilibrium). Thus, (relative) PPP seems to hold in the long-run. Furthermore, the heterogeneous agent assumption implies that the transition of exchange rate regime is continuous (smooth) rather than discrete.(Dumas, 1994) In addition, the assumption also suggests that the mean-reverting is faster when the exchange rate is farther away from its equilibrium level. And the non-constant mean-reverting speed is supported by the finding of "lazy S" mean-reverting process in actual exchange rate dynamics. (Taylor and Taylor, 2004)

Given STAR's advantages in explaining the nonlinear dynamic nature of exchange rates deviations, we therefore select a variant of STAR model to study China's exchange rate. The major task is to find not only the equilibrium exchange rate but the range of safety band.

Let s_t and μ_t denote the logarithm of the nominal and equilibrium exchange rate (domestic price of foreign currency), respectively. p_t and p_t^* are the logarithms of the domestic and foreign price levels, respectively. Since PPP implies that in equilibrium $d_t = s_t - \mu_t$ is zero. Furthermore, the time series d_t should have all roots within the unity circle if PPP holds at all. That is, d_t should be stationary with mean zero. However, the transaction costs in trade and sunk costs in (foreign) investment all make the arbitrage imperfect which largely breaks the formation mechanism of PPP and generate different exchange rate regimes. Thus the deviation d_t is rather a nonlinear process which is a random walk when the exchange rate approaches to its equilibrium (i.e. d_t approaches to zero). However, it is significantly mean-reverting towards its equilibrium level as suggested by PPP when exchange rate is far away from its equilibrium, but with an unconstant adjustment speed. Such characteristics of real exchange rate dynamics can be modeled by STAR suggested by Granger and Teräsvirta (1993) as,

$$d_t = \sum_{j=1}^{p} \beta_j d_{t-j} + \left[\sum_{j=1}^{p} \beta_j^* d_{t-j} \right] F[\theta, d_{t-d}] + \varepsilon_t \tag{4}$$

where $\{d_t\}$ is a stationary and ergodic process, $\varepsilon_t \sim iid\ (0, \sigma^2)$. $\theta \in R^+$ denotes the parameter of mean-reverting speed. $F[\theta, d_{t-d}]$ is the transition function which determines the degree of mean-reversion. $p \in N$ is the order of lag(s) and $d(= 1, 2, ..., p)$ is the order of delay.

There are, in general, two types of transition functions $F[\bullet]$ which generate two variants of STAR models. One is so-called Logistic STAR (LSTAR) whose $F[\theta, d_{t-d}] = [1 + \exp\{-\gamma d_{t-d}\}]^{-1}$; and the other is so-called Exponential STAR (ESTAR) whose $F[\theta, d_{t-d}] = [1 - \exp\left\{-\theta^2 d_{t-d}{}^2\right\}]$.

There is no general superiority between LSTAR and ESTAR. However, since most studies using STAR adopt ESTAR (for example, Taylor, Peel, and Sarno, 2001; Paya, Venetis, and Peel, 2003), we deem ESTAR, *a prior,* as the best for modelling the exchange rate dynamics.[1]

[1] According to Taylor, *et al.* (2001), there is a so-called Teräsvirta rule in the model section between ESTAR and LSTAR. For details, please see Granger and Teräsvirta (1993) and Terasvirta (1994). However, the rule can support the superiority of LSTAR only if there exists significant nonlinear structure in the third or higher order of delay, i.e. $d \succeq 3$. Since in general a time series like annual exchange rate does not have a significant time lag over 3 years, $d \leq p \leq 3$ implies that the Teräsvirta rule is not very useful in empirical studies unless an exchange rate is affected by the its history more than 3 years ago.

3 The Data and Estimation

In this section, we use (3) to estimate the equilibrium exchange rate that reflects the PPP under internal and external balances and a variant of (4) to estimate nonlinear dynamics of the China's exchange rate deviation which takes into account of the existence of transaction costs in trade and sunk costs in (foreign) investment.

3.1 Estimation of Equilibrium Exchange Rate

According to (3), to estimate the equilibrium exchange rate, we need data on TFP and interest rates. Since China's currency, Renminbi (RMB), is managed against U.S. dollars (USD), and its exchange rates with respect to other currencies are all given by the cross exchange rates, we thus focus on the exchange rate of RMB in terms of USD. That is, the RMB price of one unit of USD. The data, such as GDP, Labor, Investment, GDP deflator, and CPI during 1979-2006 are obtained from the Statistical Yearbooks of China and Bureau of Economic Analysis (of the U.S.) respectively. Capital is constructed by the perpetual inventory method using real investment. Real investment is obtained by deflating the gross domestic capital formation with GDP deflator. In addition, we construct the base year capital stock using an infinite sum of series of investment prior to the first year (1979), assuming that the average growth rate of investment of the first 10 years is a good proxy for the investment prior to the first year.

TFPs in China and the U.S are estimated by the solow residuals. That is,

$$y_t^c = a_t^c + \alpha l_t^c + \beta k_t^c + \epsilon_t^c, \qquad c = China, the\ U.S. \tag{5}$$

where the denotations of y, l, k are the same as in section 2. a is the logarithm of TFP A. In addition, GDP and capital are both measured in 1990 base. Therefore, the estimated TFPs, $\hat{a}{}_t^c$,are given by,

$$\hat{a}_t^c = y_t^c - \hat{\alpha} l_t^c - \hat{\beta} k_t^c \tag{6}$$

where hat denotes the fitted value. And the fitted value of TFP change rate (based on annual data) can be obtained by,

$$\dot{A} \doteq \hat{a}_t^c - \hat{a}_{t-1}^c \tag{7}$$

The comparison of TFP growth in China and the. U.S. during 1979∼2006 is shown in figure 1. China's TFP growth is much higher than US's which is mainly attributed to the gains from international trade and improvement in production efficiency during the transition from central planned economy to market economy. However, there is an abrupt drop in 1989 and 1990 which may reflect the political crisis in 1989. The fluctuation in the U.S. TFP growth in 1983, 1990, and 2003, though relatively trivial, is consistent with its business cycle history.

We use the lending rates in China and the U.S. as the proxies for their interest rates respectively. The lending rate in China is obtained from Financial Yearbooks (1979∼2001) and The People's Bank of China (2002∼ 2006); the U.S. counterpart can be obtained from IFS database (1979∼ 2006). By (3), we can calculate the dynamic changes of equilibrium exchange rate. To obtain the level value of equilibrium exchange rate, we need find a reasonable equilibrium exchange rate to serve as a base. Given the fact that both China and the U.S. experienced a crisis in 1990 and were believed to have completely recovered in 1994, we deem the economies of both countries reach their internal and external balances in 1994. Therefore, the PPP value of exchange rate in 1994 is chosen as the base. We just borrow the estimation from Chou and Shih (1998), that is the equilibrium exchange rate in 1994 is supposed to be 7.85.

Figure 2 plots the log-value of China's estimated equilibrium exchange rate, the "actual" annual average exchange rate, and their difference during

1979~2006.[2] Interestingly, figure 2 shows that the equilibrium exchange rate and the actual one before 1992 are very close to each other. We would rather explain this phenomenon as the limited trade and FDI activities before 1992 makes the exchange rate involatile and thus China's government can easily adjust the exchange rate based on the (low frequent) macroeconomic data. However, the surge of trade and FDI in China after 1992 makes the equilibrium exchange rate rather volatile. Thus, an almost constant exchange rate that intervened by China's government can not reflect the actual dynamics of the exchange rate any more. The constant nominal exchange with an underlying volatile equilibrium exchange rate also raises the hot debate about whether China's Renminbi is underpriced or overpriced. From our point of view, the debate, to large extent, stems from the different points of time that the researchers refer to. For example, if we are talking about the exchange rate during 2004 Renminbi should depreciate as it is well below the equilibrium level, whereas it should appreciate after 2005 for an opposite reason.

3.2 Estimation of the Band of Inaction

Before applying the STAR model to estimate nonlinear structure of China's exchange rate, we need do the two steps. The first step is to check the stationarity of the time series. A prerequisite of STAR model is that the process in study should be stationary. Given the time series is stationary, next step should identify the number of lag(s), p, in the time series and the delay variable $d \in \{1, ..., p\}$.

Step 1. The Nonaugmented Dickey-Fuller Test for Stationarity

To check the stationarity of the exchange rate series, we apply for the

[2] Before 1994, China used a two-tier exchange rater system: the official exchange rate determined by government and the market exchange rate that largely determined by the exchange rate market. Thus, an "actual" exchange rate before 1994 should be some weighted average of these two exchange rates. In this paper, we use the estimation of Xu (2008).

augmented (with constant term) Dickey-Fuller test. As shown in table 1, the DF statistic is -2.57 with a p-value of 0.11, that is, we can only reject null hypothesis that the process has a unit root under 11% significance level. Similar problems have also been encountered in other exchange rates with a relatively short time span, say $20-30$ years. However, the failure to reject the unit root hypothesis does not necessarily imply that we should accept it either. As in Taylor, *et al.* (2001), the nonlinear structure of the exchange rate may cause the seemingly unit root problem even though the exchange rate itself is in fact stationary. Taylor and Taylor (2004) also use Monte Carlo experiments to show that the failure to reject the unit root hypothesis can also be caused by the short time span of the data. Nevertheless, when we check the first order difference of the exchange rate, table 1 shows the nonaugmented DF test statistic is -2.25 with a p-value of 0.026, that is, we can reject the unit root hypothesis under at least 5% significance level. The stationarity in the first order difference of exchange rates have been found in the U.S. dollar exchange rates with respect to French Franc, Pound Sterling, and Japanese Yen. (See, Taylor, Peel, and Sarno, 2001)

Step 2. The Choice of Lags (p) and the Delays (d).

Empirically it is hard to believe that an exchange rate would be affected by its lags over three years. So we just simply compare the AIC values when the number of lag(s) is $0-3$.Table 2 shows the AIC value for each number of lag(s) and thus one lag, $p = 1$, is chosen since it can keep the minimal explanatory variables while preserving most of the explanation power for the data.

Since p is chosen to be 1, the choice of $d \in \{1, ..., p\}$ is apparently should be $d = p = 1$.

As stated in section 2.2, we choose the ESTAR model to estimate the nonlinear dynamics of China's exchange rate during 1979$\sim$2006. Particularly, given $d = p = 1$, the ESTAR is expressed as,

$$d_t = \beta[d_{t-1}] + \beta^*[d_{t-1}][1 - \exp\left\{-\theta^2 d_{t-1}{}^2\right\}] + \varepsilon_t \tag{8}$$

Similar to Taylor *et al.* (2001), we restrict β and β^* to be unity and minus unity respectively for parsimony purpose. Neither restriction is rejected under the 5% significance level. As shown in table 3, the mean-reverting parameter θ is 1.3739 which is significantly different from zero under 1% significance level.

The fitted value function of (9) is expressed as,

$$\widehat{d_t} = d_{t-1} - d_{t-1}[1 - \exp\left\{-1.9962 d_{t-1}^2\right\}] \tag{9}$$

where $\widehat{d_t}$ is the fitted value of deviation from equilibrium level.

The impulse response function of a 50% shock is plotted in figure 3. It shows that half-life of the shock is slightly more than 2 years which is similar to the 2−3 years' half-lives found in other exchange rates. The impulse response also shows clearly that the mean-reverting speed is decelerated when approaching to equilibrium level. In other words, the exchange rate is almost a random walk when it is close to its equilibrium (roughly speaking, within 5% deviation). Furthermore, figure 2 also illustrate that, roughly speaking, the arbitrage would be heavy once the deviation is above 10%. Therefore, a rule of thumb is that China's monetary authority should be alerted once the nominal exchange rate deviation from its equilibrium level by 10% or more.

4 Concluding Remarks

The nonlinear exchange rate model, STAR, is by far the best family of models which have both good theoretical foundation and good fit for empirical dynamics of real exchange rates. Various transaction costs in trade and sunk costs in (foreign) investment effectively block perfect arbitrage and generate a band of inaction. Within the band, arbitrage is not profitable and mean-reverting process towards equilibrium suggested by PPP is generally broken. Therefore, the exchange rate in the band is almost a random walk. However, if an exchange rate deviates from its equilibrium too much, then arbitrage will occur which revert the exchange rate towards the equilibrium level. Thus, (relative) PPP seems to hold. In reality, heterogeneous agents view the threshold of arbitrage differently. Nevertheless, more agents start to do arbitrage if the exchange rate is farther away from its mean, that is, the mean-reverting should be faster when deviation is enlarged. Hence, the mean-reverting process should be smooth rather than discrete and its speed is diminishing when the exchange rate is closer to its equilibrium.

In this paper, we use a variant of STAR, ESTAR, to study the exchange rate dynamics in China during 1979∼2006. Firstly, we use a general equilibrium model that considers both internal and external balances to estimate the equilibrium exchange rate. Then, by investigating the dynamic behavior of China's exchange rate, we identify that the ESTAR should have one-year lag and one-year delay. Given the particular form of ESTAR, we use nonlinear least square estimation to estimate the parameters. Based on the estimated parameters, simulation suggests that the half-life of 50% shock (deviation from equilibrium level) is slightly more than 2 years. Roughly speaking, a deviation above 10% will be facing heavy arbitrage pressure. Thus China's authority may set 10% as its picket line for exchange rate deviations.

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Figure 1. TFP Growth in China and the U.S.

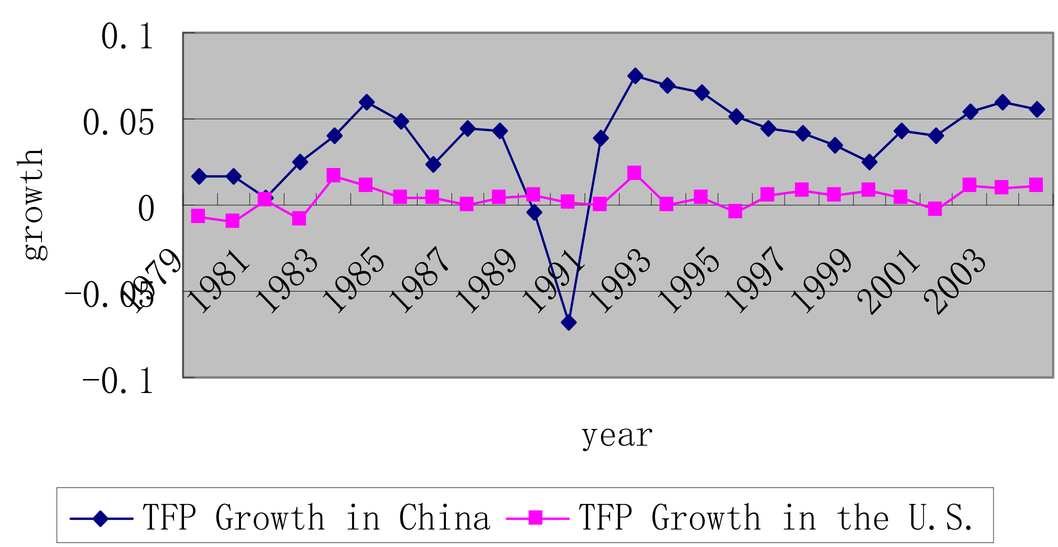

Figure 2. Equilibrium vs. Average Exchange Rate

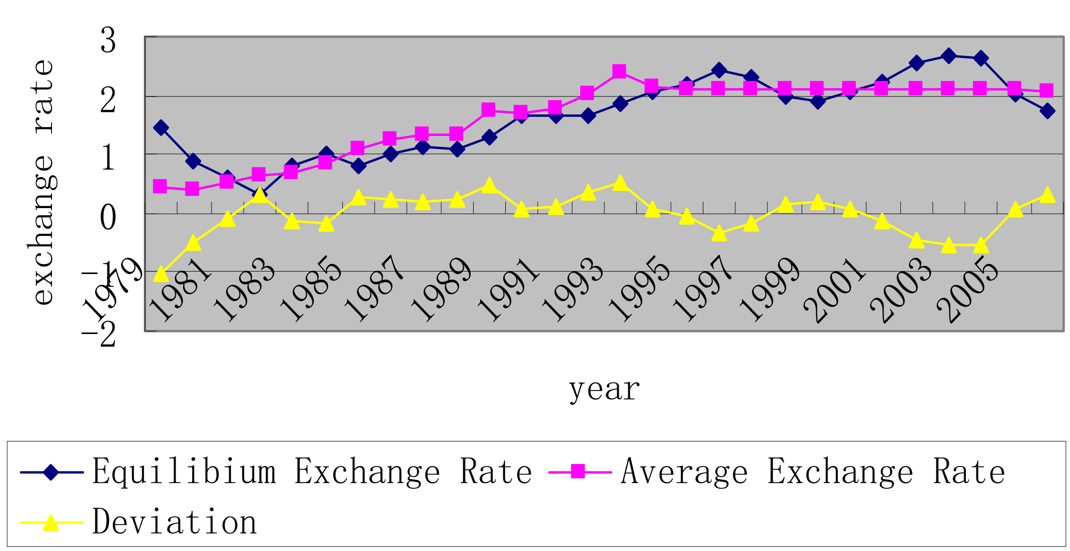

Table1. Univariate Linear Unit Root Test

	s_t	Δs_t
Dickey-Full Test Statistic	-2.5749 (augmented with constant term)	-2.2528 (nonaugmented)
Degree of Freedom	23	22
P-Value	0.1114	0.0261

Note: s_t denotes the log-level of the nominal exchange rate; Δ is the first-difference operator.

Table 2. The AIC Values for AR(p) (p=0,1,2,3)

	AR(0)	AR(1)	AR(2)	AR(3)
AIC	-27.9538	**-65.0813**	-63.1585	-61.1612

Note: The bold AIC value for AR(1) is the minimum in this table which means one period lag is selected.

Table 3. Nonlinear Estimation Results

Estimated Model:	$\widehat{s_t - \mu_t} = (s_{t-1} - \mu_{t-1}) - [s_{t-1} - \mu_{t-1}][1 - \exp\{-1.9962 \times (s_{t-1} - \mu_{t-1})^2\}]$ (Adjusted R-squared: 0.3056)		
Parameters	Restriction 1: $\beta = 1$	Restriction 2: $\beta^* = -1$	θ^{***} (=1.3739)
t-statistics	0.9929	0.0786	3.6443

Note: A hat denotes the fitted value.

Figure 3. Impulse Response