Transaction Costs and Nonlinear Adjustment of Real Exchange Rates:
STAR Model (Case Study of IRAN)

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Abstract: The recent years' studies on general equilibrium models show that equilibrium models in real exchange rate determination, considering transactions costs, imply a nonlinear adjustment process toward Purchasing Power Parity (PPP). The normal cointegration tests, in which the effects of transactions costs are ignored, often result in failure of PPP theory in the long run. In this research, considering transactions costs and nonlinear PPP adjustment, it is tried to review the adjustment trend of PPP deviations. At first, using two series of monthly and annual data for the period of 1975-2007, the linear adjustment process hypothesis of PPP deviations is tested against Smooth Transition Autoregressive (STAR) adjustment process and accordingly linear adjustment theory is rejected significantly. Then, STAR models are estimated using Newton-Raphson algorithm, and maximization of the conditional maximum likelihood function. Systematic pattern of nonlinear estimation provides strong evidence of mean-reverting behavior for PPP deviation in the long run. Though, in the short run, the PPP follows random walk behavior.

Key words: Real Exchange Rate, Purchasing Power Parity (PPP), Smooth Transition Autoregressive (STAR) model, transaction costs

INTRODUCTION

During the last decade, in most exchange rate crisis in the third world countries, especially in Mexico, East Asian countries, Russia, and Brazil, one of the effective factors was exchange rate misalignment. Ever expanding trend of markets integration has caused the cost of such crises to become doubled. In some cases they even threaten the stability of international finance. Therefore, there has been comprehensive consensus among developing countries to pursue exchange rate objectives in a way to avoid deviation of exchange rate from long run equilibrium path (misalignment) for a long period of time. It has been known that for many developing countries, exchange rate management in a band is the best alternative for exchange rate policy. In order to choose an appropriate exchange rate policy, it is necessary to study and measure exchange rate deviation from equilibrium path. Although very important, the issue has not been reached to a consensus by economists.

It should be noted that exchange rate management will be one of the key issues in foreign exchange policies for most developing countries including Iran in future. Therefore, research and measurement of the deviation of exchange rate from equilibrium path need extensive investigation and also applying various techniques. Purchasing Power Parity (PPP) theory is an important approach for determining exchange rate in the long run. Especially, since countries are not aware of foreign exchange supply and demand curves, they need to estimate the equilibrium exchange rate for which PPP is a simple method.

Nonlinear models have been mostly used in empirical economic studies in recent years comparing to the past and this is due to increasing interest of researchers to forecasting of economics parameters using nonlinear models (Tsay (2002), Clements, Franses, Swanson (2004)). Many empirical studies have provided evidences on nonlinearity and randomness of equilibrium relationship in economy. Equilibrium models for determination of real exchange rate also imply nonlinear adjustment process toward PPP. On the other hand, there are
transaction costs like brokerage-fees, bid-ask-spread, impact price, laws and regulations that affect volume and frequency of trade in financial markets. In particular, they include heterogeneous factors which result in different real transaction costs for every investor. Factors like transaction costs, industrial and institutional inflexibility and heterogeneity among economic factors have impact on economic situation. Thus, traditional cointegration tests in which transaction cost is ignored, may fail to confirm long run PPP theory.

Considering the fact that "trade can not be possible without friction" we are to present a framework for empirical analysis of PPP entailing this reality. Several equilibrium models for exchange rate determination in the presence of transaction costs have been introduced by Benninga & Protopapadakis (1998), Dumas (1992), Sercu, Uppal & Van Hulle (1995). As a result of transaction costs, persistent deviations from PPP are implied as equilibrium. Deviation from PPP follows a mean-reverting nonlinear process in which the reversion speed has direct relation with the extent of deviation from equilibrium. A nonlinear model that has such features is Smooth Transition autoregressive (STAR) model which was presented by Terasvirta (1994).

Purchasing Power Parity (PPP) Test:

The PPP test is the main approach in exchange rate determination and is related to long run rather than short run. This test, which is very important in special conditions like revision and adjustment of customs policies, is based on some assumptions like no transaction costs, tariffs, or other trade barriers. Trading all goods in international level and no structural change (e.g. war) in any countries are among the assumptions.

The theory which was introduced by Swedish economist, Cassel (1919, 1922), expresses that exchange rate can be depreciated as long as it is overpriced. Therefore, if prices double in England, while no change occurs in prices of other countries, the value of pound will half. The original theory proposes that exchange rate of two countries is a proportion of general level of prices in those countries. It means that according to "unique price law" when a commodity is valued by a currency, it should have same price in both countries (so that purchasing powers of two currencies become the same). This law expresses that nominal exchange rates should be adjusted for the purpose of equalizing the prices of goods and services among countries.

With the assumption of no transaction cost, long run PPP can be written as follows:

\[ q_t = s_t - p_t^* \]

where

- \( s_t \) is the log of nominal exchange rate (foreign price of national currency),
- \( p_t \) and \( p_t^* \) are the log of foreign and domestic price indices, respectively,
- and \( q_t \) is deviation from PPP.

Cointegration is a distinguished approach for long run PPP test. Assuming non-stationary \( p_t \), \( s_t \), and \( p_t^* \), cointegration test needs \( q_t \) to be stationary.

Cointegration implies on mean-reverting behavior in no transaction cost condition. In this case \( q_t \) has linear trend which means adjustment is continuous and has a constant speed. With presence of transaction cost, \( q_t \) follows nonlinear approach.

Nonlinear Adjustment Toward PPP:

Examples of effect of transaction costs on PPP tests have been studied by Pippenger and Davutyan (1990). Recently, Michael et al (1994) reviewed nonlinear behavior of adjustment in terms of autoregressive models. The nonlinear adjustment approach can be expressed by STAR model (Granger and Terasvirta, 1993). In this case, adjustment may occur in every period but the speed of adjustment changes proportional to the extent of deviation from equilibrium level. Regime changes in this model occur gradually and not abruptly. The STAR models are under consideration for the following reasons:

1. In these models, adjustment process is smooth rather than discrete.
2. As decision making in macro level is done by several economic agents, if we suppose that the decision making takes place dichotomously, it is unlikely that they can change each others’ behaviors. Thus as was stated by Terasvirta (1994), the process of regime change occurs smooth rather than discrete.
3. The processes of statistical modeling for STAR model are completely developed.

Analysis of STAR Model:

Generally, a nonlinear dynamic model with an additive disturbance term can be stated as follows:
\[ y_t = f(z_t; \theta) \cdot \varepsilon_t \]

In which \( z_t = (w'_t, x'_t)' \) is a vector of explanatory variables of \( w'_t = (1, y_{t-1}, \ldots, y_{t-p})' \) and the vectors of strictly independent variables \( x'_t = (x_{1t}, \ldots, x_{kt})' \). \( \varepsilon_t \approx \text{iid}(0, \sigma^2) \) is disturbance term in the model. Smooth Transition Regression (STR) model is derived from a work done by Bocan & Watt (1971). They introduced two regression groups and a model in which transition from one group to another is carried out smoothly and is shown by a tangent hyperbolic function. The function is similar to two normal cumulative and logistic distribution functions. This type of function was suggested by Maddala (1997) for the first time and became a common benchmark since then.

Generally, STR model can be explained as follows; this is a special form of the model (1):

\[
y_t = \varphi'z_t + \theta'z_tG(\gamma, c, s_t) + \varepsilon_t = \{\varphi + \theta G(\gamma, c, s_t)\} \cdot z_t + \varepsilon_t = 1, \ldots, T \tag{2}
\]

in which \( z_t \) is obtained from equation (1) and \( \varphi = (\varphi_0, \varphi_1, \ldots, \varphi_m)' \) and \( \theta = (\theta_0, \theta_1, \ldots, \theta_m)' \) are parametric vectors and \( \varepsilon_t \approx \text{iid}(0, \sigma^2) \).

In transition function \( G(\gamma, c, s_t) \), \( \gamma \) is slope parameter and \( c = (c_1, \ldots, c_k)' \) is a vector of location parameters and \( c_1 \leq \ldots \leq c_k \). Transition function is a bounded function of transition variables \( s_t \) that are continuous in both parameters space and for all values of \( s_t \).

Equation (2) shows that the model can be interpreted as a linear model with random coefficients \( \varphi + \theta G(\gamma, c, s_t) \) different in time. In this model, \( s_t \) controls changes in time.

Transition function in a logistic model has a standard form as follows:

\[
G(\gamma, c, s_t) = (1 + \exp\left\{-\gamma \prod_{k=1}^{K} (S_t - C_k)\right\})^{-1}, \gamma > 0 \tag{3}
\]

Equations (2) and (3) jointly result in Logistic STR (LSTR) model. In this model the most possible states are for \( k=1 \) and \( k=2 \). When \( k=1 \), the parameters \( \varphi + \theta G(\gamma, c, s_t) \) change monotonically as a function of \( s_t \) from \( \varphi \) to \( \varphi + \theta \).

For \( k=2 \), the parameters \( \varphi + \theta G(\gamma, c, s_t) \) change symmetrically around mid-point, \((c_1 + c_2) / 2\). In this case, the minimum value of logistic function lies in range \((0, 0.5)\). When \( \gamma \rightarrow \infty \), the parameter reaches to zero and when \( c_1 = c_2 \) and \( \gamma < \infty \), the minimum figure equals 0.5.

Parameter \( \gamma \) controls the slope and \( c_1 \) and \( c_2 \) show the location of transition function. When \( k=1 \), LSTR1 model will be capable of characterizing asymmetric behavior. For example, suppose \( S_t \) is a measure of
business cycles, then LSTR1 model can explain procedures whose dynamic features in recovery paths are different from those of recession paths. This model expresses that transition from one regime to another can be performed smoothly. When \( k=2 \), LSTR(2) is formed. It happens when movement and location dynamism of adjustment procedure is similar in high and low values of \( S_t \) and different in the middle. It is noticeable that when \( \gamma = 0 \), transition function is \( G(\gamma, c, S_t) = \frac{1}{2} \), thus STR model is converted into linear model and when \( \gamma \to \infty \) STR model is converted into Switching Regression (SR) model.

In LSTAR2 model when \( \gamma \to \infty \), the model is converted into SR model with three regimes in which two outer regimes are identical and the middle regime is different from the other two. Another type of LSTR2 model is Exponential Smooth Transition Autoregressive (ESTAR) in which transition function is as follows:

\[
G(\gamma, c, S_t) = 1 - \exp\{-\gamma (S_t - c)^2\}, \gamma > 0
\]

If \( x_t \) is omitted from equation (2) and \( S_t = y_t - d \) or \( S_t = \Delta y_t - d \) and \( d > 0 \), STR model is converted into a one variable STAR model. The performing PPP tests are one of the applications of STR and STAR models.

LSTAR models were introduced in time series studies done by Ghan & Tong in 1998 in which the normal cumulative distribution is considered as transition function. One variable STAR models are applied in modeling of asymmetric behavior of macroeconomic variables such as industrial production and unemployment rate or nonlinear behavior of inflation.

Based on the above-mentioned researches, in this research LSTAR1 and LSTAR2 models are used to estimate exchange rate behavior and also transaction cost function. LSTAR2 is a substitution for ESTAR model, as they both possess same features for explaining exchange rate behavior.

**Literature Review:**

In Iranian literature, there are few studies on real exchange rate estimation and its deviation from equilibrium level (PPP) with presence of transaction cost and nonlinear pattern of deviations. In these studies, purchasing power parity test in Iranian foreign exchange market is performed using cointegration methods. However, there have been several studies on this topic in foreign countries.

Timo Terasvirta (1994) in a paper titled “Specification, Estimation and Evaluation of Smooth Transition Autoregressive Models”, application of two groups of nonlinear autoregressive models (LSTAR and ESTAR) was reviewed. In addition, the features of a model like simple statistical tests, linearity test in terms of smooth transition autoregressive (STAR), determination of delay parameter and also choosing between LSTAR and ESTAR models were examined. The result shows that if the linearity hypothesis is rejected, STAR can be chosen. On the other hand, a few nonlinear time series can be explained by both models LSTAR and ESTAR. The techniques are simple and have better performance in small samples. It has been emphasized that Threshold Autoregressive (TAR) model can also be used for nonlinear data but applications of STAR models seem more of interest than TAR model.

Michael Panos, Robert Nobay, and David A. Peel (1997), in a research named “Transaction Cost and Nonlinear Adjustment of Real Exchange Rate: an Empirical Investigation”, studied the behavior of exchange rate considering transaction costs and using annual and monthly data and ESTAR model. They used Dumas results about the deviation in nonlinear process; the larger the deviation from PPP, the stronger the tendency to move back to equilibrium. They concluded that with presence of transaction cost, deviation in nonlinear process follows mean-revert behavior and real exchange rate will stay far from equilibrium for a long time. Timo Terasvirta (2005) in another paper, “Forecasting Economic Variables with Nonlinear Models”, reviewed a number of nonlinear models and presented important information about the forecast process in these models. He concluded that the power of nonlinear models in density forecasts is more appropriate, otherwise there is no major difference between linear and nonlinear models. But forecast in linear model is more robust than that of nonlinear model. In some cases only nonlinear models can be used and linear models do not have enough efficiency and vice versa.
In a study by Sophie Béreau et al (2008) titled "Nonlinear Adjustment of the Real Exchange Rate Towards its Equilibrium Value: A Panel Smooth Transition Error Correction Modeling", using STR panel model, the convergence of exchange rate process towards equilibrium was studied. They found that there are two different processes among developing countries and industrial countries. Misalignment in developing countries is small and adjustment toward equilibrium is nonlinear. While in industrial countries, since misalignments are homogeneous, their adjustment toward equilibrium level is linear.

Mohamad Boutahar et al (2008) in their study called “A Fractionally Integrated Exponential Star Model Applied to the US Real Effective Exchange Rate” reviewed the real effective exchange rate dynamic models for the period of (1978-2002). The study used the features of FESTAR models on explaining simultaneous nonlinearity which are applied for out-of-sample forecast. They concluded that for out-of-sample US exchange rate forecasts, FESTAR is better than linear and random walk models.

**Research Method:**

In this research, the model is used for the annual and monthly data of the period of 1975-2007. After estimation of the model, the transaction cost function will also be derived. According to the abovementioned researches, it is supposed that the deviation from PPP can be explained by the following equations:

\[ q_t = k + \sum_{j=1}^{p} \pi_j q_{t-j} + (k^* + \sum_{j=1}^{p} \pi_j^* q_{t-j}) \times \left\{ 1 + \exp \left[ -\gamma (q_{t-d} - c^*) \right] \right\}^{-1} \quad \text{LSTAR1} \quad (5) \]

\[ q_t = k + \sum_{j=1}^{p} \pi_j q_{t-j} + (k^* + \sum_{j=1}^{p} \pi_j^* q_{t-j}) \times \left\{ 1 + \exp \left[ -\gamma (q_{t-d} - c^*)^2 \right] \right\}^{-1} \quad \text{LSTAR2} \quad (6) \]

In the above equations, \( q \) is the deviation from PPP which can be seen in equation 1, too. Equations \( F(q_{t-d}) = 1 + \exp \left[ -\gamma (q_{t-d} - c^*)^2 \right] \) and \( F(q_{t-d}) = 1 + \exp \left[ -\gamma (q_{t-d} - c^*) \right] \) are transition equations (nonlinear part of the model) and show transaction costs.

In order to achieve the objectives of the research and perform different hypothesis tests, the appropriate models are expressed as follows. These models have also been used in empirical studies of other countries.

\[ \Delta q_t = k + \lambda q_{t-1} + \sum_{j=1}^{p-1} \phi_j \Delta q_{t-j} + (k^* + \lambda^* q_{t-1} + \sum_{j=1}^{p-1} \phi_j^* \Delta q_{t-j}) \times \left\{ 1 + \exp \left[ -\gamma (q_{t-d} - c^*) \right] \right\}^{-1} \quad (7) \]

\[ \Delta q_t = k + \sum_{j=1}^{p} \pi_j \Delta q_{t-j} + (k^* + \sum_{j=1}^{p} \pi_j^* \Delta q_{t-j}) \times \left\{ 1 + \exp \left[ -\gamma (\Delta q_{t-d} - c^*)^2 \right] \right\}^{-1} \quad (8) \]

In the above equations, \( \lambda \) and \( \lambda^* \) are crucial parameters and are used for both unit root test and the comparison of speed of regime transition in short run versus long run. In addition, with estimation of transition function, transaction costs function will also be derived.

Since transaction costs imply a nonlinear adjustment behavior for exchange rate, the first hypothesis that should be tested is linearity test. In equation 3 (transition function), when \( \gamma = 0 \), the model will be converted into a nonlinear model. Thus, linearity hypothesis can be expressed as \( H_0: \gamma = 0 \). Terasvirta (1994) presented the following decision making rule for linearity hypothesis test against LSTAR and ESTAR assumptions:

1. Estimating by ordinary least squares (OLS) the following artificial regression:
2. Testing the following null hypothesis:

\[ H_0 = \beta_1 = \beta_2 = \beta_3 = 0 \]

This is the null hypothesis for linearity test and it means that if the null hypothesis is rejected, the hypothesis of linearity will not be valid.

3. Using the ordinary F-test as an approximation of Lagrange coefficient test for its high power of the test (in final results, F is a sign of this test)

4. Choosing transition variable: considering all potential transition variables including dependent variable, independent variables and their delay variables and trend, the above test is done. Any variable that offers more significant test in rejecting null hypothesis of linearity is considered as transition variable and is shown by * sign in final results.

5. Choosing the type of model between LSTAR1 and LSTAR2 with the assumption of rejected linearity hypothesis:

When the linearity of the model is rejected, the model which is a better specifier will be chosen (between LSTAR1 and LSTAR2). The decision is made based on the 3 following hypotheses:

1. test \( H_0^4 : \beta_3 = 0 \)
2. test \( H_0^3 : \beta_2 = 0 \mid \beta_3 = 0 \)
3. test \( H_0^2 : \beta_1 = 0 \mid \beta_2 = \beta_3 = 0 \)

These tests are also done for the artificial regression (4). In final results, the probabilities of the above tests are presented with the labels F4, F3, and F2, respectively. With the assumption of rejected linearity of the model, it is possible to continue for estimation of the nonlinear model. Then a grid search is done to estimate the starting values of \( \gamma \) and \( c \). Choosing proper initial figures is very important in the algorithm of parameters estimation in nonlinear STR models. Grid search makes a linear grid for \( c \) and a logarithmic-linear grid for \( \gamma \). Then for each figure of \( \gamma \) and \( c \), the residuals sum of squares is estimated and finally the figures conformed to least sum of squares are considered as initial figures. Afterwards, the parameters of the model will be estimated by Newton-Raffson algorithm using maximization of conditional maximum likelihood function.

**Linearity Test:**

The beginning phase in specifying the STR model is to choose linear AR model. Thus, at first, linear part of the model, AR(p), is expressed in VAR framework by finding optimum number of lags using Akaic, Schwartz and Hannan-Quin measures.

The results for equations 7 and 8 using annual and monthly data are as follows:

For annual data:

- Linear part of equation 8
  \[ \Delta q_t = 0.03 + 0.375\Delta q_{t-1} - 0.348\Delta q_{t-2} \]

- Linear part of equation 7
  \[ \Delta q_t = -37.222 + 0.13q_{t-1} + 0.285\Delta q_{t-1} - 0.393\Delta q_{t-2} \]

For monthly data:

- Linear part of equation 8
  \[ \Delta q_t = 0.041 + 0.004\Delta q_{t-1} - 0.104\Delta q_{t-2} - 0.072\Delta q_{t-3} \]

- Linear part of equation 8
  \[ \Delta q_t = -6.032 + 0.13q_{t-1} - 0.115\Delta q_{t-2} \]
Having found the linear part of the model, artificial regression no (4) will be created and null hypothesis (1) on linearity of the model is tested. The results of the tests are presented in tables 1 to 4. It is worth to say that the figures in the tables are not the F statistics figures but probabilities of the F statistics. The first columns in the tables show transition variables, the second columns show the probabilities of F tests for null hypothesis of linearity. For each potential trend variable, the test has been calculated. F4, F3, and F2 tests are the tests for hypotheses on 5th assumption of Trasvierta decision making process. As it is clear, for both annual and monthly data, the linearity null hypothesis is significantly rejected and alternative hypothesis, smooth transition, has been accepted. Tables 1 and 2 are related to equation 8. For annual data, differentiation of deviation from PPP with one lag and for monthly data differentiation of deviation from PPP with 2 lags is considered as transition variable. It is interesting that the suggested model for both data series is LSTAR2. This indicates that in addition to smooth transition of deviation from PPP and direct relationship between speed of reversion to equilibrium with deviation from equilibrium, for both positive and negative deviations, conformity and tendency towards equilibrium is completely symmetric. Tables 3 and 4 are related to equation 7. For annual data, deviation from PPP with one lag and for monthly data, deviation from PPP is considered as transition variable. In this case, the suggested model for both monthly and annual data is LSTAR1. Though, since the probabilities F2, F3 and F4 for annual data have not been calculated, it is possible LSTAR2 to be used, instead. Thus autoregressive linear model such as AR or ARMA which have been used for specification of reversion process toward PPP equilibrium are not appropriate models for this case. Because one of their features is continuity and constant speed of adjustment process from which deviation from PPP does not obey.

### Table 1: The result of linearity test for annual data and equation 2

<table>
<thead>
<tr>
<th>Transition Variable</th>
<th>F</th>
<th>F4</th>
<th>F3</th>
<th>F2</th>
<th>Suggested Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dq(t-1)*</td>
<td>0.0011970</td>
<td>0.0095884</td>
<td>0.0041712</td>
<td>0.55651</td>
<td>LSTR2</td>
</tr>
<tr>
<td>Dq(t-2)</td>
<td>0.30525</td>
<td>0.22336</td>
<td>0.60187</td>
<td>0.20600</td>
<td>Linear</td>
</tr>
<tr>
<td>TREND</td>
<td>0.050683</td>
<td>0.15291</td>
<td>0.032642</td>
<td>0.46035</td>
<td>Linear</td>
</tr>
</tbody>
</table>

### Table 2: The result of linearity test for monthly data and equation 2

<table>
<thead>
<tr>
<th>Transition Variable</th>
<th>F</th>
<th>F4</th>
<th>F3</th>
<th>F2</th>
<th>Suggested Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dqq(t-1)</td>
<td>0.85625</td>
<td>0.84547</td>
<td>0.67800</td>
<td>0.49019</td>
<td>Linear</td>
</tr>
<tr>
<td>Dqq(t-2)*</td>
<td>0.00032703</td>
<td>0.018614</td>
<td>0.0066811</td>
<td>0.036276</td>
<td>LSTR2</td>
</tr>
<tr>
<td>Dqq(t-3)</td>
<td>-</td>
<td>0.0000000062</td>
<td>0.00000027</td>
<td>0.027685</td>
<td>Linear</td>
</tr>
<tr>
<td>TREND</td>
<td>0.099118</td>
<td>0.96570</td>
<td>0.87403</td>
<td>0.79358</td>
<td>Linear</td>
</tr>
</tbody>
</table>

### Table 3: The result of linearity test for annual data and equation 1

<table>
<thead>
<tr>
<th>Transition Variable</th>
<th>F</th>
<th>F4</th>
<th>F3</th>
<th>F2</th>
<th>Suggested Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dg(t-1)</td>
<td>0.0049959</td>
<td>0.52904</td>
<td>0.000366</td>
<td>0.29833</td>
<td>LSTR2</td>
</tr>
<tr>
<td>Dg(t-2)</td>
<td>0.040790</td>
<td>0.040428</td>
<td>0.98781</td>
<td>0.026509</td>
<td>LSTR1</td>
</tr>
<tr>
<td>q(t)</td>
<td>0.24598</td>
<td>0.67101</td>
<td>0.26634</td>
<td>0.053431</td>
<td>Linear</td>
</tr>
<tr>
<td>q(t-1)*</td>
<td>0.00000000</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>LSTR1</td>
</tr>
<tr>
<td>TREND</td>
<td>0.0054771</td>
<td>0.016273</td>
<td>0.85804</td>
<td>0.0040190</td>
<td>LSTR1</td>
</tr>
</tbody>
</table>

### Table 4: The result of linearity test for monthly data and equation 1

<table>
<thead>
<tr>
<th>Transition Variable</th>
<th>F</th>
<th>F4</th>
<th>F3</th>
<th>F2</th>
<th>Suggested Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dqq(t-1)</td>
<td>0.63241</td>
<td>0.11742</td>
<td>0.92402</td>
<td>0.88627</td>
<td>Linear</td>
</tr>
<tr>
<td>Dqq(t-2)</td>
<td>0.0007896</td>
<td>0.0009931</td>
<td>0.027255</td>
<td>0.39987</td>
<td>LSTR1</td>
</tr>
<tr>
<td>qqq(t)*</td>
<td>0.0000495</td>
<td>0.0054182</td>
<td>0.008304</td>
<td>0.001059</td>
<td>LSTR1</td>
</tr>
<tr>
<td>qqq(t-1)</td>
<td>-</td>
<td>-</td>
<td>0.03127</td>
<td>-</td>
<td>Linear</td>
</tr>
<tr>
<td>TREND</td>
<td>0.18020</td>
<td>0.085310</td>
<td>0.32632</td>
<td>0.49638</td>
<td>Linear</td>
</tr>
</tbody>
</table>

### Model Estimation and Transaction Cost Function:

As it was mentioned earlier, the model is estimated using Newton-Rafson algorithm. In this base, estimation of equation 7 and 8 for annual and monthly data are as follows: (numbers in parentheses show t statistics probability related to significance of the coefficients)

Estimation of equation 7 based on LSTAR1 model and annual data

\[
\Delta q_t = 213602.59 + 0.9997 \Delta q_{t-1} + 0.0003 \Delta q_{t-1} + 0.00048 \Delta q_{t-1} + (-428108.49 + 0.0006 \Delta q_{t-1} - 0.0006 \Delta q_{t-1} - 0.001 \Delta q_{t-1}) \\
(0.000) (0.000) (0.17) (0.017) (0.000) (0.0135) (0.17) (0.017)
\times [1 + \exp\{-0.00217(q_{t-1} - 451.66)\}]^{-1}
\]
Estimation of equation 7 based on LSTAR1 model and monthly data

\[ \Delta q_t = -3.733 + 0.012q_{t-1} + 0.023\Delta q_{t-1} - 0.081\Delta q_{t-2} + (-2327.7 + 2.38q_{t-1} - 0.95\Delta q_{t-1} - 0.55\Delta q_{t-2}) \]
\[ (0.302) (0.3) (0.655) (0.114) (0.000) (0.000) (0.000) (0.0017) \]
\[ \times \left\{ 1 + \exp[9.39(q_t - 970.1)] \right\}^{-1} \]  

Estimation of equation 8 based on LSTAR2 model and annual data

\[ \Delta q_t = 8.056 - 0.353\Delta q_{t-1} + 0.39\Delta q_{t-2} + (-160.79 + 1.594\Delta q_{t-1} - 1.68\Delta q_{t-2}) \]
\[ (0.612) (0.186) (0.04) (0.14) (0.018) (0.000) \]
\[ \times \left\{ 1 + \exp[74.48(\Delta q_{t-1} - 353.67) \times (\Delta q_{t-1} - 90.351)] \right\}^{-1} \]  

Estimation of equation 8 based on LSTAR2 model and annual data

\[ \Delta q_t = 142.02 + 0.38\Delta q_{t-1} - 7.11\Delta q_{t-2} - 4.37\Delta q_{t-3} + (-139.5 - 0.39\Delta q_{t-1} + 7.06\Delta q_{t-1} - 4.35\Delta q_{t-1}) \]
\[ (0.000) (0.177) (0.000) (0.000) (0.000) (0.17) (0.000) (0.000) \]
\[ \times \left\{ 1 + \exp[8.59(\Delta q_{t-2} - 19.004) \times (\Delta q_{t-2} - 118.43)] \right\}^{-1} \]  

In summary it can be said that the results are compatible with Dumas (1992) explanation about the adjustment process of PPP deviation. Because, at first, for annual and monthly exchange rate time series, linear adjustment process in terms of autoregressive model with smooth transition is rejected and on the other hand based on equation 10, constraint \( \lambda = 0 \) is not rejected but constraint \( \lambda^* = 0 \) is rejected. This indicates random walk behavior for smaller deviations than \( q_t = 970.1 \) and faster adjustment for larger deviations from PPP. In long run there is a tendency toward equilibrium. As it was mentioned before, nonlinear part is an indicator of transaction costs, thus in all of the estimated equations above, coefficient in fractions can be drawn against transition variable to determine transaction costs. Charts 1 and 2 show transaction costs functions.

**Chart 1:** Transaction Costs (Transition Function for Monthly Data)
Chart 2: Transaction Costs (Transition Function for Annual Data)

The comparison of the charts shows that transition for annual deviation from PPP is slower than transition in monthly deviation. In other words, transition speed among regimes for annual time series is smaller than that of monthly time series.

Conclusion:

Most of the empirical studies show that huge deviations from PPP are along with low power of unit root test. This, indeed, is an indication of failure of empirical test to support long run PPP (Lothian and Taylor 1996). According to the current opinion, this may happen as a result of not considering transaction costs in the models. Therefore, in this research a nonlinear adjustment process based on Dumas analysis is presented. The process involves transaction costs and more tendencies of larger deviations to move back to equilibrium. Due to the existing of transaction chains, the process is divergent and thus real exchange rate will be far from parity most of the time. Although deviations from PPP tend to be persistent and larger, dynamic process forces reversion to equilibrium in the long run.

In this research, using annual and monthly data for the period of 1976-2002, a linear model in term of LSTAR1 and LSTAR2 is tested. For both time series, linearity is rejected significantly. Estimation of the parameters indicates that there is random walk behavior for small deviation from PPP, but for larger deviations, adjustment is faster. In addition, transaction cost for annual and monthly series implies that the speed of transition between regimes is much faster in annual data than for the monthly data.

REFERENCES


