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ARDL Approach to the Exchange Rate Overshooting in Taiwan

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Abstract. This paper re-examines Dornbusch's (1976) sticky-price monetary model to exchange rate determination by employing both conventional Johansen's (1988, 1990, 1994) maximum likelihood cointegration test and the ARDL Bound test by Pesaran, Shin, and Smith (2001) for the monthly data of Taiwan over the period 1986:01∼2003:04. Ambiguous results are found for the long-run equilibrium relationship between the NTD/USD exchange rate and macro fundamentals. With the advantage that ARDL Bound test incorporates both I(1) and I(0) series, we conclude our empirical evidence that there is no long-run equilibrium relationship between exchange rates and macro fundamentals. Moreover, for the short-run dynamic response, the result from the ARDL-UECM-MAIC (1, 10, 10, 8, 10) setting supports the overshooting of currency depreciation as pre-described by Dornbusch (1976). However, this overshooting phenomenon does not exist the current month, but one month after.

Key words: ARDL, bound test, overshooting, exchange rate, macro fundamental

JEL Classification: C32, B22, E44

1. Introduction

Ever since the crash of the Bretton Woods Agreement in 1973, almost all countries in the world have abandoned a fixed exchange rate system and adopted a floating one instead. Dramatic changes in exchange rates are observed every day and sometimes the fluctuations can be as high as a couple of percentage points. Changes in exchange rates imply adjustments in costs or gains, which affect the profitability of multinationals and increase exchange exposure to enterprises and financial institutions. Taiwan is an island where natural resources are scarce, and they rely heavily on international trade with other countries in the world. A well-controlled manner over the trends of exchange rate fluctuations will assist enterprises and financial institutions in evaluating the performance of investments, financing, and hedging and thus reduce their operational risks.

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There are many factors affecting changes in exchange rates, including (but not limited to) economic, political, and psychological aspects, and these factors interact with each other. Research studies on exchange rates stem from the equilibrium theory of supply and demand. In the 1960s the theory of optimum currency introduced by Fleming (1962) and Mundell (1963)—based on the control over exchange rates and various hypotheses of elasticity of capital mobility—became the mainstream of thought for theories governing exchange rate determination of that time. Since the launching of floating exchange rates in the 1970s, economists have been investigating the determination of foreign exchange rate in the basis of monetary stock, (e.g., Frenkel, 1976; Dornbusch, 1976; Bilson, 1978; Frankel, 1979; Dornbusch and Fisher, 1980; Hooper and Morton, 1982). In their so-called monetary approach to exchange rate determination, the major determinants of the level of exchange rate include money supply, national income, interest rates, inflation, trade balance, and financial deficit.[1] Besides, Branson (1977) further introduced the asset portfolio model for the determination of exchange rate. Although empirical evidence from Meese and Rogoff (1983) dominated the forecasting effectiveness of foreign exchange determination theories,[2] contemporary economists still believe in the robustness of monetary theories and apply these models to the study of exchange rate movement. In the past few years, some represented supportive literature related to monetary models to exchange rate determination can be found in Dutt and Ghosh (2000), Miyakoshi (2000), Taylor and Peel (2000), Kilian and Taylor (2001), Rapach and Wohar (2002), Rogoff (2002), Karfakis (2003), Veronese (2003), Dornbusch (2004), Jimoh (2004), Papell (2004), Rapach and Wohar (2004), Simwaka (2004) and West (2004). Based on various currencies, they all somewhat support a short run dynamic or long run equilibrium relationship between exchange rate and those macro fundamentals. Using NTD/USD exchange rate of NTD against one USD as an example, we re-examine the monetary school to exchange rate determination. The variables considered in this study include exchange rate and four macro fundamentals of money supply, national income, interest rates, and inflation rate.

We begin with figure 1 illustrating the movement of the NTD/USD exchange rate. According to the figure, there were two radical changes between 1986 and 2003. The first one was the continuous NTD appreciation in 1986–1988[3] and the second change was the drastic depreciation of the NTD due to Asian Financial Crisis in 1997. Such dramatic changes in the exchange rate created negative effects on the fundamentals of Taiwan's macroeconomics. As the impacts on international trade imposed by fluctuations of exchange rates become greater and grater nowadays, the issue on exchange rate has become the centerpiece for market participants and academic scholars alike.

The illustration of figure 2 shows the comparison of the monthly percentage change of NTD/USD with relative prices in Taiwan and the U.S. which confirms the sticky-price monetary model proposed by Dornbush (1976).[4] In other words, the fluctuations of exchange rates are greater than those of commodity prices. The relative price levels are sticky in the short-run. Such an empirical finding further supports the assumptions of this paper that price levels are fixed in the short-run[5] and will not change significantly in accordance with adjustments in policies.

All the major central banks of the world have been nudging down interest rates since 2000 in an effort to provide a stable investment environment and to boost their economies.

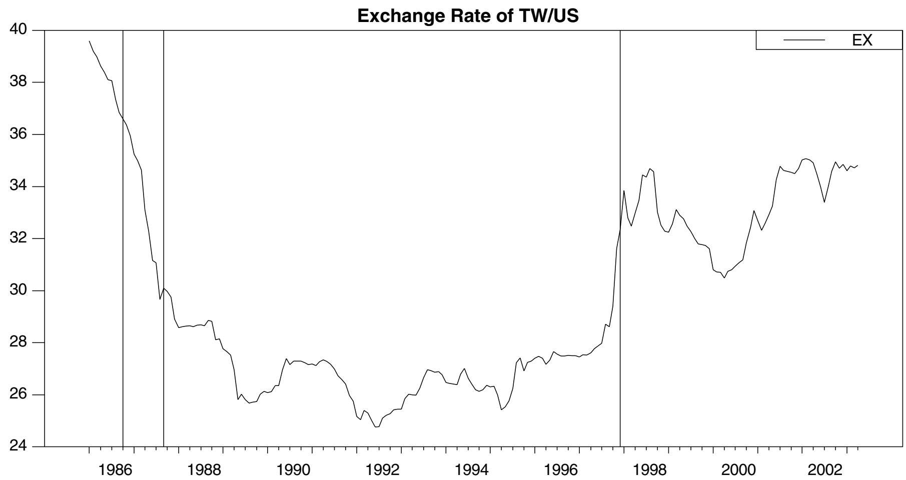

Figure 1. The trend of the NTD/USD exchange rate during 1986:01–2003:04. *Note*: Tow dramatic changes on NTD/USD: (1) Continuous appreciation of NTD during 1986–1988; (2) Sharp depreciation in 1997 caused by Asian Financial Crisis.

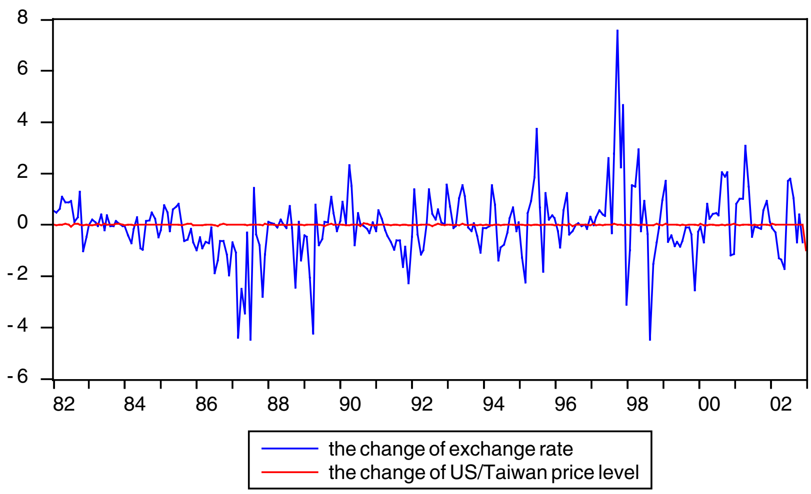

Figure 2. Comparison of the percentage changes of NTD/USD with the relative price of Taiwan to the US.

The monetary environment is loose after dozens of interest rate reductions. Figure 3 shows that the interest rates in the monetary markets of Taiwan and the U.S. are both close to zero. This draws a big question: Is the zero interest rate a positive or negative factor to economic growth in Taiwan? The decline of interest rates in Taiwan is partly in line with the global trend and partly a result of sluggish domestic economies and a lack of sufficient loans and investments by financial institutions. Figure 3 shows the ups and downs of interest rates

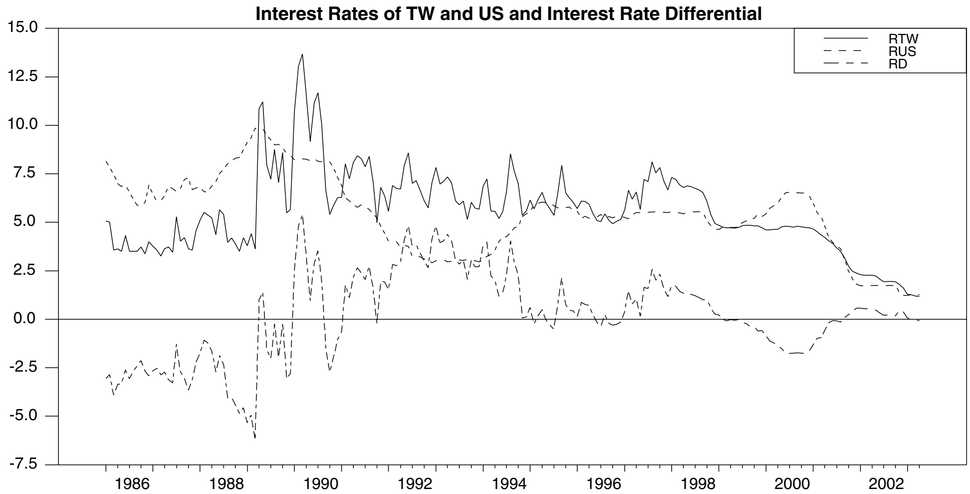

Figure 3. The interest rates of Taiwan and the US and their interest rate differentiation during 1986:01–2003:04.

in Taiwan and the U.S. It is worth investigating whether we can apply uncovered interest rate parity to reflect the interest gaps of the two countries and thus predict the possible depreciation effects of currencies.

A theory proposed by Dornbush (1976) explaining the abnormal fluctuations of exchange rates describes that the short-run extraordinary fluctuations are due to the short-run sticky-price in the commodity and labour markets. The adjustments of prices in the commodity and labour markets are much slower than those of interest rates and exchange rates in the financial markets. Therefore, various shocks to the economy, such as an increase in the money supply, will trim down the interest rates and cause capital outflow and as a result will depreciate the home currency. However, in the long-run, according to UIRP, the reductions of interest rates will always accompany an anticipated appreciation of the exchange rates.[6] Therefore, the changes in exchange rates caused by such shocks from an increase in money supply will create an over-reaction of short-run currency depreciation at an intensity that is much larger than the long-run level, although the exchange rate will gradually resume its long-run equilibrium. This phenomenon is called "exchange rate overshooting"[7] and this theory helps to explain the sharp fluctuations in the exchange market on a daily basis.

There are differing schools attempting to explain the overshooting of exchange rates, including capital mobility, loan-able fund, and liquidity preference theories. The Dornbush's (1976) model focused on the short-run overshooting of exchange rates resulting from differing speeds of adjustments between markets.[8] Over the past 27 years, the overshooting model has been enormously studied by economists.[9] Driskill (1981), Bhandari (1985), Akiba (1996), Goldfajn and Gupta (2001), and Papell (2004) all supported Dornbush's model with empirical evidence. Bahmani-Oskooee and Kara (2000) states that the depreciation of the Turkish Lira lasted as long as 30 years and the exchange rate their dropped from a two-digit number of 13 to a staggering six-digit of 400,000.[10] This implies that overshooting can be a long-run phenomenon as well.

To reveal the dynamic relationship between the exchange rate and macroeconomic variables, this paper uses the NTD/USD exchange rate to examine Dornbush's (1976) monetary model on exchange rate determination. Instead of merely applying conventional cointegration,[11] the purpose of this paper is to re-examine the exchange rate determination model by employing both conventional Johansen's (1988, 1990, 1994) maximum likelihood cointegration test and the relatively new method of ARDL (autoregressive distributed lag) Bound test by Pesaran, Shin, and Smith (2001) to investigate the long-run and short-run impacts of monetary shocks to exchange rates during 1986:01–2003:04. In other words, we examine the overshooting of NTD when there is an unanticipated expansionary monetary policy in Taiwan and the long-run equilibrium relationship between NTD/USD exchange rate and macro fundamentals of Taiwan and the US.

The organization of the paper is as follows. The second section provides a brief view of the theoretical models. The third section introduces the econometric methodology. Data sources and empirical results are presented in the fourth section. The conclusion of the study is in the fifth section.

2. Theoretical models

This paper attempts to adopt a model with a long-run view based on the quantity theory of money demand, the relative purchasing power parity (PPP), and uncovered interest rate parity (UIRP). We apply the conventional monetary model to exchange rate determination, as shown in Eq. (1) after a logarithmic-transformation that the long-run equilibrium relationship of the exchange rate is determined by the relative money supply, relative real income, nominal interest rate differential, and the relative inflation rates.

$$e_t = \beta_0 + \beta_1(M_t' - M_t^*) + \beta_2(Y_t' - Y_t^*) + \beta_3(R_t' - R_t^*) + \beta_4(\Pi_t' - \Pi_t^*) + \mu_t \qquad (1)$$

where e indicates the nominal spot exchange rate under the "American quotation" (i.e. one USD worth of NTD). M, Y, R and Π indicate, respectively, money supply, industrial production index (a proxy variable for income), short-run interest rate, and inflation rate (calculated based on the consumer price index, $\Pi_t = \ln CPI_t - \ln CPI_{t-1}$). All the variables in the model, except for interest rate and inflation rates, are transformed with a natural logarithm.[12] Monthly data running from 1986:01 to 2003:04 were obtained from the International Financial Statistics of the IMF.

Using NTD/USD as example, we pre-describe the relationship between exchange rate and macro fundamentals. Dornbusch's (1976) monetary exchange rate model implies that the increase of money supply in Taiwan will reduce the relative purchasing power of the NTD and thus push the NTD toward depreciation. Moreover, the greater the economic growth of Taiwan, the more products needed by Taiwanese people. This accelerates the demand for the USD and thus pushes the NTD toward depreciation. On the other hand, when the interest rates of Taiwan are higher than the global levels, foreign investor will invest more in the Taiwan's financial market. The increasing of capital inflow will end up to an appreciation of NTD. The increases in both interest rate and exchange rate can be referred as "Double Rise of the NTD". By the PPP, however, when the domestic price of Taiwan

Table 1. Comparison among various monetary models of exchange rate determination $e_t = \beta_0 + \beta_1(M'_t - M^*_t) + \beta_2(Y'_t - Y^*_t) + \beta_3(R'_t - R^*_t) + \beta_4(\Pi'_t - \Pi^*_t) + \mu_t$

Model	Scholar	Coefficient
Chicago	Frenkel (1976)	$\beta_3 = 0, \beta_4 > 0$
	Bilson (1978)	$\beta_3 > 0, \beta_4 = 0$
	Combine Bilson and Frenkel:	$\beta_3 + \beta_4 = \gamma > 0, \beta_3 \geq 0, \beta_4 \geq 0$
Keyensian	Dornbusch (1976) sticky price	$\beta_3 < 0, \beta_4 = 0$
Real interest differential	Frankel (1979):	$\beta_3 < 0, \beta_4 > 0$

is higher than the global price levels, the NTD will usually depreciate. Summarizing the above statements, we presume that exchange rate is positively correlated with each of the macro fundamentals, namely money supply, industrial production index, and inflation and is negatively correlated with the interest rate. According to the model proposed by Dornbusch (1976), the relationships among the exchange rate and macro fundamentals prescribed in Eq. (1) are as follows: $\beta_1 > 0, \beta_2 > 0, \beta_3 < 0, \beta_4 > 0$.[13] However, the relationships among exchange rate and those macro fundamentals are shown different based on different assumptions by various representative economic schools in the 1970s, which can be shown as Table 1.

3. Methodology and empirical results

The purpose of this study is to examine whether there is a long-run equilibrium relationship between the NTD/USD exchange rate and the macro economic fundamentals and to analyze whether there is an overshooting of the NTD in the short-run as a result of the non-anticipated increase in money supply. The integrated tests are the maximum likelihood estimation devised by Johansen (1988, 1990, 1994) and the bound test in the ARDL model proposed by Pesaran, Shin and Smith (2001). The conventional method of Johansen cointegration test needs to assure that variables are all non-stationary and integrated at the same order, whereas, the bound test procedure has the advantage that it can be applied irrespective of whether the variables are $I(1)$ or $I(0)$.

3.1. Stationary test

Various newly developed unit root tests have shown that macro variables are unsure an $I(1)$ or I(0) series. The results of those stationary tests are always conflict with each other. To confirm this argument, this paper employs six unit root tests, i.e., Dickey and Fuller (1981, ADF), Phillips and Perron (1988, PP), Elliott, Rothenberg and Stock (1996, DFGLS), Elliott, Rothenberg and Stock (1996, ERS), Ng and Perron (2001, NP), and Kwiatkowski et al. (1992, KPSS), to fully analyse the stationarity of each variable.[14] Among these, the null of KPSS test is testing for $I(0)$, the null of the rest five tests are testing for $I(1)$. Modified Akaike information criterion (Modified-AIC or MAIC) suggested by Ng and Perron (2001)

Table 2. The results of various unit root tests based on MAIC and Bartlett kernel

	e		M		y		r		π	
ADF										
Level	−0.447	(1)	1.111	(12)	−0.297	(14)	−1.764	(8)	−2.255**	(14)
difference	−3.214***	(7)	−2.360**	(12)	−24.651***	(0)	−14.613***	(0)	−24.226***	(0)
DF-GLS										
Level	−0.532	(1)	0.566	(12)	0.552	(14)	−0.806	(8)	−0.656	(18)
difference	−2.112**	(7)	0.121	(11)	−0.308	(15)	−2.637***	(13)	−23.953***	(0)
ERS										
Level	49.778	(1)	132.04	(12)	68.280	(14)	13.703	(8)	0.334***	(0)
difference	2.727**	(7)	64.005	(12)	2.581**	(0)	0.243***	(0)	0.385***	(0)
NP										
Level	−0.524	(1)	0.803	(12)	0.652	(14)	−0.857	(8)	1.087	(25)
difference	−2.017**	(7)	0.217	(11)	3.248	(15)	−0.567	(13)	13.312	(21)
PP										
Level	−2.037	(6)	−2.278	(6)	−9.956***	(8)	−3.119***	(9)	−19.274***	(15)
difference	−9.783***	(1)	−10.262***	(14)	−53.443***	(76)	−18.600***	(25)	−128.14***	(92)
KPSS										
Level	0.535**	(11)	1.6755***	(11)	1.425***	(10)	0.447*	(10)	0.199	(17)
difference	0.796***	(6)	0.239	(5)	0.144	(51)	0.148	(26)	0.160	(37)

Notes:

1. e, m, y, r, and π are the symbols for the logarithm of exchange rate, money supply differential, industrial production differential, short-run interest rate differential, and inflation rate differential, respectively.
2. ***, **, and * denote significant at 1, 5, and 10% levels, respectively.
3. The critical values for 1, 5, and 10% levels of ADF, DF-GLS, ERS, NP, PP, and KPSS are (−3.9935; −3.4271; −3.1368), (−3.4660; −2.9180; −2.6190), (4.0172; 5.6454; 6.8710), (MZ_t: −3.42; −2.91; −2.62), (−3.9920; −3.4264; −3.1364), and (0.216; 0.146; 0.119), respectively.
4. The test statistic of the NP test is MZ_t.
5. The numbers in the parentheses of ADF, DF-GLS, ERS, and NP are the appropriate lag lengths selected by MAIC (Modified Akaike information criterion) as suggested by Ng and Perron (2001), whereas the numbers in the parentheses of PP and KPSS are the optimal bandwidths decided by the Bartlett kernel of Newey and West (1994).
6. The null of the KPSS test is to test for $I(0)$, the null of the other five tests are to test for $I(1)$.
7. Based on the decision procedure suggested by Dolado, Jenkinson and Sosvilla-Rivero (1990), the appropriate models for the level and the first difference are both with trend and intercept, respectively.

for unit root of ADF, DF-GLS, ERS, and NP and Bartlett kernel based criterion proposed by Newey and West (1994) for PP and KPSS are applied to determine the optimal number of lags and optimal bandwidth, respectively, based on the "principle of parsimony" in our unit root tests since the estimation might be biased if the lag length and bandwidth are pre-designated without rigorous determination.

The results of the six unit root tests are summarized in Table 2. With the exception that exchange rate is most likely a $I(1)$ series, all the macro fundamentals are shown to be inconclusive. For example, the money supply differential (m) is found to be $I(1)$ series from ADF, PP and KPSS and is even non-stationary in the first difference under the tests of DF-GLS, ERS and NP. Income differential (y) and interest rate differential (r), on the other hand, are both I(1) from ADF, ERS and KPSS, $I(0)$ from PP, and integrated more that two orders under NP test. Inflation rate differential (π), however, shows most likely a I(0) series, which is from the tests of ADF, ERS, PP and KPSS. The mix results among variables suggest that variables considered in our model are integrated of different order, which implies that variables are inconclusive of being I(1) or I(0).

3.2. Johansen's cointegration test

In order to compare the differences of conventional and innovative cointegration tests, despite the noticeably inconsistent results of I(1) and I(0), we first employ the Johansen's maximum likelihood technique to test for the long-run equilibrium relationship among variables in our monetary model. Johansen's (1988, 1990,[15] 1994)[16] five multi-variance Gaussian Vector Auto-regression (VAR) models with ECM, are presented as below:

$$H_0 : \Delta Y_t = \Gamma_1 \Delta Y_{t-1} + \cdots + \Gamma_{k-1} \Delta Y_{t-k+1} + \alpha\beta' Y_{t-1} + \Phi D_t + \varepsilon_t \quad (1988) \tag{2}$$

$$H_1^* : \Delta Y_t = \Gamma_1 \Delta Y_{t-1} + \cdots + \Gamma_{k-1} \Delta Y_{t-k+1} + \alpha(\beta', \beta_0)(Y'_{t-1}, 1)' + \Phi D_t + \varepsilon_t \quad (1990) \tag{3}$$

$$H_1 : \Delta Y_t = \Gamma_1 \Delta Y_{t-1} + \cdots + \Gamma_{k-1} \Delta Y_{t-k+1} + \alpha\beta' Y_{t-1} + \mu_0 + \Phi D_t + \varepsilon_t \quad (1990) \tag{4}$$

$$H_2^* : \Delta Y_t = \Gamma_1 \Delta Y_{t-1} + \cdots + \Gamma_{k-1} \Delta Y_{t-k+1} + \alpha(\beta', \beta_1)(Y'_{t-1}, t)' + \mu_0 + \Phi D_t + \varepsilon_t \quad (1994) \tag{5}$$

$$H_2 : \Delta Y_t = \Gamma_1 \Delta Y_{t-1} + \cdots + \Gamma_{k-1} \Delta Y_{t-k+1} + \alpha\beta' Y_{t-1} + \mu_0 + \mu_1 t + \Phi D_t + \varepsilon_t \quad (1994) \tag{6}$$

Our decision criterion of determining the appropriate model follows the decision procedure proposed by Nieh and Lee (2001), among the hypotheses $H(r)$ and $H*(r)$, for five different models and is presented in the following way:

$$H_0(0) \to H_1^*(0) \to H_1(0) \to H_2^*(0) \to H_2(0) \to H_0(1) \to H_1^*(1) \to H_1(1) \to H_2^*(1) \to H_2(1) \to \cdots \to \cdots \to H_0(p-1) \to H_1^*(p-1) \to H_1(p-1) \to H_2^*(p-1) \to H_2(p-1).$$

where H represents the null hypothesis, the numbers in the parentheses indicate the cointegration rank, and the suffixes 0, 1, and 2 represent models of 1988, 1990 and 1994, respectively.

The empirical findings for the long-run relationship with the consideration of a linear trend and a quadratic trend among exchange rate and macro fundamentals are summarized in Table 3. The results indicate that there exists a long-run cointegration equilibrium relationship among exchange rate and macro fundamentals. Their cointegration relationship is presented without a constant and time-trend in the difference equation, which implies no linear trend and quadratic trend exists in the level relationship. Moreover, four cointegration vectors are found in their equilibrium relationships.

Table 3. Determination of cointegration rank in the presence of a linear trend and a quadratic trend

	Model 1 H_0 (17)		Model 2 H_1^* (17)		Model 3 H_1 (175)		Model 4 H_2^* (17)		Model 5 H_2 (17)	
Rank	$T_0(r)$	$C_0(5\%)$	$T_1^*(r)$	$C_1^*(5\%)$	$T_1(r)$	$C_1(5\%)$	$T_2^*(r)$	$C_2^*(5\%)$	$T_2(r)$	$C_2(5\%)$
$r = 0$	103.29	59.5	139.13	76.1	113.75	68.5	144.80	87.3	138.99	77.7
$r \leq 1$	65.19	39.9	83.42	53.1	63.16	47.2	93.72	63.0	88.19	54.6
$r \leq 2$	37.79	24.3	52.79	34.9	35.77	29.7	52.82	42.4	49.53	34.6
$r \leq 3$	15.49	12.5	30.06	20.0	17.70	15.4	26.92	25.3	24.31	18.2
$r \leq 4$	3.00	3.8	12.08	9.2	0.28	3.8	9.49	12.3	9.44	3.7

Notes:

1. $T_0(r)$, T_1^*(r), $T_1(r)$, $T_2^*(r)$, and $T_2(r)$ denote the LR test statistics for all the nulls of $H(r)$ versus the alternative of $H(p)$ of Johansen's five models.
2. $C_0(5\%)$, $C_1^*(5\%)$, $C_1(5\%)$, $C_2^*(5\%)$, and $C_2(5\%)$ are the 5% LR critical values for Johansen's five models, which are extracted from Osterwald-Lenum (1992).
3. The model selection follows Nieh and Lee's (2001) decision procedure, diagnosing models one by one until the model that cannot be rejected for the null.
4. The bold number with underline indicates the selection of the rank in the presence of a linear trend and quadratic trend.
5. VAR length is 17 for all the models, which is selected based on the smallest number of AIC.

3.3. *ARDL bound test*

In order to avoid a false result from conventional cointegration tests when co-existing of $I(1)$ and $I(0)$ series, Pesaran, Shin and Smith (2001) constructed ARDL model and applied the Bound test in a critical bound to examine the long-run equilibrium relationship among variables.[17] Owing to its advantages of not only solving the problem of series consisting of differing orders but tackling small-sample problem, ARDL bound testing method has been widely applied in various studies in recent years.[18]

The ARDL model also takes into account the error correction term in its lagged period. The analysis of error corrections and autoregressive lags fully covers both the long-run and short-run relationships of the variables tested. As the error correction term in the ARDL model does not have restrictive error corrections, ARDL is an Unrestricted Error Correction Model (UECM).

The Bound test of ARDL-UECM proposed by Pesaran, Shin and Smith (2001) applies the fundamental principles of Johansen's five error correction multi-variance VAR models. Considering the presence of constant, time-trend, and restrictive condition, there are also five models presented as follows.

Model 1: no intercepts; no trends:

$$\Delta y_t = \alpha' \Delta X_t + \sum_{j=1}^{p-1} \beta_j' \Delta Z_{t-j} + \pi_{yy} y_{t-1} + \pi_{yX.X} X_{t-1} + \varepsilon_t \tag{7}$$

Model 2: restricted intercepts; no trends:

$$\Delta y_t = \alpha' \Delta X_t + \sum_{j=1}^{p-1} \beta_j' \Delta Z_{t-j} + \pi_{yy}(y_{t-1} - \mu_y) + \pi_{yX.X}(X_{t-1} - \mu_X) + \varepsilon_t \tag{8}$$

Model 3: unrestricted intercepts; no trends:

$$\Delta y_t = c_0 + \alpha' \Delta X_t + \sum_{j=1}^{p-1} \beta_j' \Delta Z_{t-j} + \pi_{yy} y_{t-1} + \pi_{yX.X} X_{t-1} + \varepsilon_t \tag{9}$$

Model 4: unrestricted intercepts; restricted trends:

$$\Delta y_t = c_0 + \alpha' \Delta X_t + \sum_{j=1}^{p-1} \beta_j' \Delta Z_{t-j} + \pi_{yy}(y_{t-1} - \gamma_y t) + \pi_{yX.X}(X_{t-1} - \gamma_X t) + \varepsilon_t \tag{10}$$

Model 5: unrestricted intercepts; unrestricted trends:

$$\Delta y_t = c_0 + c_1 t + \alpha' \Delta X_t + \sum_{j=1}^{p-1} \beta_j' \Delta Z_{t-j} + \pi_{yy} y_{t-1} + \pi_{yX.X} X_{t-1} + \varepsilon_t. \tag{11}$$

This paper aims to test whether there is an overshooting of NTD/USD exchange rate as a result of un-anticipated increase in money supply and to examine whether there exist long-run equilibrium relationships between the NTD/USD exchange rate and macro fundamentals of two countries. The monetary model to exchange rate determination as represented in Eq. (1) is appropriate to our examination, which can be rewrite as Eq. (12).

$$e_t = \beta_0 + \beta_1 m_t + \beta_2 y_t + \beta_3 r_t + \beta_4 \pi_t + \varepsilon_t \tag{12}$$

The symbol e represents the spot exchange rate of the NTD/USD. The symbols m, y, r, and π indicate differentials in, respectively, money supply, industrial production index, short-run interest rate, and inflation rate of Taiwan and the US. ε_t is an independent identical distribution (i.i.d.) of white noise.

Since the first model, presenting without a constant and a time-trend, of the Johansen cointegration models is decided by Nieh and Lee (2001) procedure, this paper adopts model 1 of Eq. (7) for our short-run and long-run ARDL model estimation. To formulate an ARDL-UECM model, the monetary model of Eq. (12) is further rewritten as following form.

$$\begin{aligned}\Delta e_t = {} & \sum_{j=1}^{n_1} b_j \Delta e_{t-j} + \sum_{j=0}^{n_2} c_j \Delta m_{t-j} + \sum_{j=0}^{n_3} d_j \Delta y_{t-j} + \sum_{j=0}^{n_4} f_j \Delta r_{t-j} \\ & + \sum_{j=0}^{n_5} g_j \Delta \pi_{t-j} + \phi_1 e_{t-1} + \phi_2 m_{t-1} + \phi_3 y_{t-1} + \phi_4 r_{t-1} + \phi_5 \pi_{t-1} + \varepsilon_t \end{aligned} \tag{13}$$

The null of this ARDL model test is $H_0 : \phi_i = 0$, for all i ($i = 1, 2 \ldots 5$), and the alternative hypotheses is H_1: At least one ϕ_i, for all i ($i = 1, 2 \ldots 5$), does not equal zero. If the F-statistic of our ARDL bound testing is higher than the upper value, then we reject the null and conclude that there is a long-run equilibrium relationship among variables. On the other hand, if the F-statistic is lower than the lower value, we cannot reject the null of

Table 4. ARDL bound testing for cointegration analysis

Computed F-statistic: 1.5791 (lag structure, $k = 1, 10, 10, 8, 10$)
Critical bound's value at 5% (Lower: 2.26 and Upper: 3.48)
Unrestricted intercept and no trend in the model
Pesaran, Shin and Smith (2001) p. 301 Table CI. (V) CaseV.

no cointegration relationship among variables, which implies a speculative bubble exists in the exchange market. However, if the F-statistic falls within the upper value and lower value, then we cannot reach any definite conclusions.[19]

Since lag lengths are crucial for the credibility of our empirical evidence. We again use the MAIC criterion suggested by Ng and Perron (2001) to select the appropriate lag lengths. The results from our lag-length selection are 1, 10, 10, 8, and 10 for variables of spot exchange rate of NTD/USD, and differentials in money supply, industrial production index, short-run interest rate, and inflation rate of Taiwan and the US. Therefore, we constitute an ARDL-UECM-MAIC (1, 10, 10, 8, 10) model for our long-run and short-run examination of the exchange rate determination.

Tables 4 and 5 indicate the estimated results of the ARDL-UECM-MAIC models. According to Table 4, the *F* value of the bound test by Pesaran, Shin and Smith (2001) is 1.5791, which is far below the insignificant (0) level.[20] This indicates that there is no long-run equilibrium relationship between exchange rates and macro fundamentals. In other words, it is not appropriate in determining the trend of NTD/USD movement in the long-run by the macroeconomic indicators, as prescribed by monetary schools. This seems to imply that the fluctuations of the NTD do not completely depend on changes of the macro fundamentals, but influenced by the speculative bubbles.

The finding in this paper that there is no long-run co-movement between the exchange rate and macro fundamentals seems to topple all the traditional monetary theories in the exchange rate determination developed in 1970s since the floating exchange rate regime. Besides, numerous empirical studies have argued that exchange rate should co-move in the long-run with macro fundamentals. The application of conventional cointegration techniques without rigid pretest of the stationarity seems pivotal for the biasness of the long-run equilibrium relationship among variables in those empirical studies.[21] This paper applies newly-developed bound test of the ARDL model incorporating both (1) and (0) series, which is more persuasive in describing the movement of the exchange rate. In fact, the result supports the argument by Meese and Rogoff (1983) that the traditional monetary models cannot predict the trends of exchange rate and the exchange rate movement indeed follows a random walk process.

Veronese (2003) argued that the dynamics of the exchange rate movements, under the conditions of perfect foresight, UIRP, and sticky product price, corroborated the existence and importance of Dornbusch's (1976) extraordinary findings. According to Dornbusch's (1976) OS model, exchange rates tend to overreact in the dynamic adjustment under an expansionary monetary shock. The short-run depreciation is thus greater than its long-run levels.

The empirical tests of this paper to depict the short-run movement of NTD/USD caused by changes in money supply are based on Eq. (13), which represents our ARDL-UECM-MAIC (1, 10, 10, 8, 10) setting. In this setup the short-run effects of money supply on the

Table 5. Full information estimate of the ARDL (1, 10, 10, 8, 10) model based on MAIC criteria

	Lag order										
Variables	0	1	2	3	4	5	6	7	8	9	10
Δe		0.2325									
		(2.91)***									
Δm	−12.50	2.4465	−0.6021	−1.1775	1.0217	0.9639	−0.3961	−1.6746	−1.0512	2.0917	0.0511
	(−10.8)***	(1.61)	(−0.53)	(−1.05)	(0.89)	(0.81)	(−0.33)	(−1.39)	(−0.84)	(1.72)*	(0.04)
Δy	−1.8793	−0.5460	0.1005	0.2066	0.1600	−0.0199	0.3745	0.8932	1.4362	2.0263	0.9437
	(−4.39)***	(−0.64)	(0.12)	(0.25)	(0.20)	(−0.03)	(0.48)	(1.18)	(2.10)**	(3.57)***	(2.27)**
Δr	−0.0144	−0.1120	0.0023	−0.0230	−0.0194	0.0092	−0.0407	0.0150	−0.0698		
	(−0.58)	(−3.87)	(0.08)	(−0.81)	(−0.70)	(0.34)	(−1.57)	(0.59)	(−2.75)		
$\Delta \pi$	1.0419	12.928	13.163	12.888	14.060	17.018	17.099	15.463	9.7027	5.0243	1.2255
	(0.36)	(0.73)	(0.82)	(0.89)	(1.09)	(1.52)	(1.79)*	(1.96)*	(1.59)	(1.16)	(0.47)
ex_{t-1}		0.0016									
		(0.95)									
m_{t-1}		0.1224									
		(0.71)									
y_{t-1}		−0.0783									
		(−0.10)									
r_{t-1}		0.0058									
		(0.30)									
π_{t-1}		−16.89									
		(−0.85)									

Note:

1. The number inside the parentheses is the t-value.
2. ***, **, and * denote significant at 1, 5, and 10% levels, respectively.
3. The appropriate lag lengths are selected by MAIC (Modified Akaike information criterion) as suggested by Ng and Perron (2001).

exchange rate are inferred by the sign and significance of c_j, whereas the long-run effects are inferred by the sign and significance of ϕ_2.

The empirical evidence in Table 5 shows that there is a significant negative response (-12.50) of the NTD/USD exchange rate to the monetary shock. Such a response of NTD/USD turns to be positive, 2.45, after one month and dampen thereafter. These findings indicate that the NTD/USD exchange rate responds to monetary shock in the short-run. However, the negative response of the current period implies that the expansionary monetary policy does not cause an immediate depreciation of the NTD. Instead, it brings the NTD toward appreciation contemporarily. The impact of monetary shock to NTD/USD turns out to be positive after one month and dampen thereafter indicating that the NTD/USD exchange rate reverses to depreciate and overshoot in the short-run. The findings of this paper support the overshooting of currency depreciation as pre-described in the sticky-price monetary exchange rate model by Dornbusch (1976). However, this overshooting phenomenon exists one month after.

Our findings also rule out the possibility of predicting the long-run exchange rates movement based on the monetary exchange rate model. The symbol ϕ_2 and its insignificant characteristics show that there is no long-run equilibrium relationship between the NTD/USD exchange rate and macro fundamentals. This argument is consistent with the findings from the Bound testing that there is no cointegration relationships exists as shown in Table 4.

4. Conclusion

This paper re-examines Dornbusch's (1976) sticky-price monetary model to exchange rate determination by employing both conventional Johansen's (1988, 1990, 1994) maximum likelihood cointegration test and the newly-developed ARDL Bound test by Pesaran, Shin, and Smith (2001). Contrary results are found for the long-run equilibrium relationship between the NTD/USD exchange rate and macro fundamentals. Since various unit root tests show that variables considered in this study are inconclusive of being $I(1)$ or $I(0)$, with the advantage that ARDL Bound test incorporates both $I(1)$ and $I(0)$ series, we conclude our empirical evidence that there is no long-run equilibrium relationship between exchange rates and macro fundamentals. In other words, it is not appropriate in determining the trend of NTD/USD movement in the long-run by the macroeconomic indicators.

Moreover, for the short-run dynamic response, the result from the ARDL-UECM-MAIC (1, 10, 10, 8, 10) setting supports the overshooting of currency depreciation as pre-described in the sticky-price monetary exchange rate model by Dornbusch (1976). However, this overshooting phenomenon does not exist the current month, but one month after.

In our Dronbusch's (1976) overshooting examination, we investigate whether the shock of monetary supply causes an overshoot of exchange rate depreciation over it's long-run mean. The monetary model adopts the money supply differential between two countries (Taiwan and the US in our example) as a key factor for determining the exchange rate movement. The AR terms of money supply differential in the ARDL overshooting model describe the lag-lead implication of the effect of monetary shock on the exchange rate level. With the acknowledge that monetary interventions from both countries' monetary authorities (central bank of Taiwan and the FED of the US) significantly affect the exchange rate level, in order to add extra academic value, further research for exchange rate determination should be down by incorporating central bank's intervention as an impact innovation (e.g., add dummy variables to proxy for the interventions).

Notes

1. The flexible price version of monetary model represented by Frenkel (1976) and Bilson (1978) is classified as Chicago model, the sticky price version represented by Dornbusch (1976) and Frankel (1979) are so-called Keyensian model and real-interest—rate model, respectively. All mentioned above consider mainly four factors (money supply, national income, interest rates, inflation) as determinants of exchange rate movement. Dornbusch and Fisher (1980) and Hooper and Morton (1982) further consider other factors, such as trade balance and financial deficit, into their extended monetary model.
2. The evidence from Meese and Rogoff (1983) found that the random walk model is the most effective one to catch the trend of exchange rates.
3. The variation of the NTD/USD exchange rate during 1986–1988 was basically the consequence of the "Plaza-Louvre intervention accord". The revaluation since July 1986 of the NTD/USD exchange rate mainly showed a linked reaction of interference appreciation by the YEN to the USD as caused from the G-5 "Plaza intervention accord" (1986/09/22).
4. The major assumption to the sticky price monetary model is: small-open economic system, absolute capital that is completely mobile, a floating foreign rate, and sticky commodity prices.
5. The assumption of short-run sticky prices suits more towards analyzing a country with stability in its related price levels.
6. Rising commodity prices for a long period will make real money supply go lower, and therefore help lift interest rates and capital outflow up, further invoking a revaluation of the domestic currency.
7. For a related illustration of the model, please be referred to Rogoff (2002) and Veronese (2003).
8. However, Levin (1999) made a slight adjustment to the model by Dornbush (1976) and discovered that the range of raising (devaluing) the short-run rate will be smaller than the one from raising the long-run rate, which reveals undershooting.
9. Twenty-five years after Dornbush (1976) and Rogoff (2002) presents a figure showing the citations per year for the studying of the overshooting model.
10. Turkish Lira further depreciates from 400,000 in year 2000 to 1,500,000 in year 2004 under the "American quotation". The number presented as the "due rate" from "American quotation" implies the Turkish lira again the USD.
11. Ever since Bailie and Selover (1987), scholars have applied conventional cointegration (including Engle and Granger (1987) and Johansen (1988)) to study and test each determinate model of the exchange rate.
12. The logarithm transformation of variables with exception of interest rates and inflation rates (these two rates have already been in the form of percentage rate) is consistent with the original conventional monetary model of Dornbusch (1976) or Dornbusch (1987).
13. However, the relationships among exchange rate and those macro fundamentals are shown different based on different assumptions by various representative economic schools in the 1970s, as tabulated in Table 1.
14. The test statistic of NP test is MZ_t in this paper.
15. The 1990 equation forms are from Johansen and Juselius (1990).
16. Johansen's (1988, 1990, 1994) five VAR models fully consider the presence of a linear trend and a quadratic trend.
17. A series of studies by Pesaran and Shin (1995a, 1995b) and Pesaran, Shin and Smith (1996, 2001) argued that as long as both $I(1)$ and $I(0)$ series exist in a system, conventional cointegration tests, i.e., two-stage residual-based method by Engle and Granger (1987) and maximum likelihood approximation by Johansen (1988, 1990, 1994), might bias the results of the long-run equilibrium interactions among variables.
18. ARDL has been applied extensively; please refer to the empirical literature, such as Abbot, Darnell, and Evans (2001, Britain, exchange rate); Bentzen and Engsted (2001, Denmark, energy demand), Ghatak and Siddiki

(2001, India, exchange rate), Atkins and Coe (2002, U.S. and Canada, Fisher effect), Bahmani-Oskooee and Ng (2002, HK, money demand), Fedderke and Liu (2002, South Africa, capital outflow and capital flight), Tang and Nair (2002, Malaysia, import demand), and Vita and Abbott (2002, U.S., savings and investment), Bahmani-Oskooee and Goswami (2003, Taiwan, J-curve), and Pattichi and Kanaan (2004, Balassa-Samuelson Hypothesis).

19. For the upper and lower bound values for the F-statistic of the ARDL bound test, please refer to pages 300–301 in Pesaran, Shin and Smith (2001).
20. Since the independent variable k is 4, the 5% bounding values of the upper and lower bounds of $I(1)$ and $I(0)$ are 3.48 and 2.26, respectively, in the first ARDL model of Pesaran, Shin and Smith (2001).
21. For example, the so-called "yes man" unit-root test by Dickey and Fuller's (1981) is hard to reject an $I(1)$ result.

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