A Structural Threshold Model of the Exchange Rate under Optimal Intervention

Hsiu-Yun Lee* and Hung-Pin Lai

Department of Economics, National Chung Cheng University, No, 168, University Rd, Chia-Yi, Taiwan

Abstract

By considering a social trade-off between targeting the exchange rate and minimizing intervention costs, nonlinear exchange rate dynamics can be captured by a structural threshold model. This article provides a theory-based empirical exchange rate model and shows how to put the model into an empirical investigation. To estimate the structural threshold model, we propose a two-step procedure which separately estimates the permanent and temporary fundamentals of the foreign exchange market. A demonstration of our approach is applied to 1981Q3-2008Q3 Taiwan's foreign exchange market, with a brief review of its monetary policies and central bank given prior. Estimation results are consistent with theoretical predictions and many intervention operations of Taiwan's central bank are successfully identified.

Keywords: structural threshold model, exchange rate, managed float, intervention

* Tel.: 886 5 2720411-34106; fax: 886 5 2720816, e-mail address: ecdsyl@ccu.edu.tw. The authors thank the discussants and participants at the 11th Annual Conference of the Taiwan Econometric Association, and the 2nd, 3rd, and 5th Conference of Money, Exchange Rates, and Dynamic Equilibrium in Taiwan for their helpful feedback and comments. A grant from the NSC of Taiwan (NSC97-2752-H-194-001-PAE) is also gratefully acknowledged.

1. Introduction

The explanation and the forecast of the process of exchange rates are probably the most challenging missions in macroeconomic analysis. Since the pioneering work of Engel and Hamilton (1990), many found that nonlinear regime-switching models tended to econometrically outperform over linear models in studying the dynamics of the exchange rate. Nonetheless, after taking the rational expectations of the market participants into account, few studies have derived a nonlinear process of the exchange rate from a theoretical model of international finance before estimating the process. This article will bridge the gap between a theoretical model of the exchange rate determination and its econometric model.

To explain the nonlinearity of the exchange rates process, some authors are notified of one unique characteristic of the foreign exchange market — its stochastic official manipulation. The famous historical instance of official intervention is the European Exchange Rate Mechanism (ERM). More recent instances are those countries under intermediate exchange rate regimes, such as Argentina, Colombia, Czech Republic, Denmark, Egypt, Hungary, Indonesia, Singapore, and Thailand. Even the float intervenes in some cases. The Bank of Japan intervened in its foreign exchange market to suppress the yen's appreciation in September 2010 and to stabilize the yen after the tragic earthquake in March 2011.

There are a variety of works related to official intervention. On the one hand, nonlinear models such as regime-switching models by Lewis (1995), Mundaca (2001), Kirikos (2002), Beine, Laurent and Lecourt (2003), Lee and Chang (2007), and Beine, de Grauwe and Grimaldi (2009), threshold autoregression (TAR) type models by Suardi (2008) and Beine, de Grauwe and Grimaldi (2009), and autoregressive conditional heteroskedasticity (ARCH) type models by Beine, Bénassy-Quéré and

Lecourt (2002), Dominguez, (1998, 2006), and Beine, Janssen and Laurent (2009) are estimated in the studies of exchange rate processes under official interventions. On the other hand, there are several pure theoretical works, especially from a continuous time framework, on studying the nonlinear process of the exchange rate under official intervention, e.g., Bertola and Caballero (1992), Lewis (1996), and Coles and Philippopoulos (1997) among others. Most of the research is left either as a purely theoretical exercise or as an empirical work estimated with some loose implications from a theoretical model.

The difficulty in solving an endogenous nonlinear model is definitely one reason for the rareness of close connection between a theoretical model and an empirical one.[1] Previous empirical studies either lack theoretical basis or solve theoretical models under naive expectations. For the latter, the exchange rate expectations of the market are formed as if there are no future regime changes or as if no other players exist in the market, that is, participants ignore stochastic interventions of central banks as well as fundamentalists ignore the transactions from co-existent chartists/noise traders.

Davig and Leeper (2007) note that expectations of future policy changes generate an "expectation formation effect" and affect the rational-expectation equilibrium of the current regime. Among the limited research modeling the expectation formation effect, Lee and Chang (2007) consider an exchange rate swinging between an official peg and market forces. In the presence of the central bank's intervention, the exchange rate is backward-looking pegged, while in the absence of the intervention, it is forward-looking determined by the equilibrium of the exchange change market. They

[1] Another difficulty in estimating the exchange rates under stochastic central bank interventions lies in the lack of official intervention data.

show that the stochastic interventions of the central bank change the expectations of the market participants, and therefore the exchange rate dynamics in the absence of intervention are different from those under a clean float. Although consistent with the regime-switching process of concerned variables, Lee and Chang (2007) do not model the nonlinear decisions of their central banks by economic rationales and thus their model must be classified as an exogenous regime-switching model.

By assuming a conditional intervention rule from a purely theoretical framework, Hsieh (1992) derives two devaluation rate processes for the regime with and without the central bank's intervention in an endogenous regime-switching model.[2] In fact, most of the literature *assumes* an intervention reaction function rather than *derives* an intervention reaction function. There are two exceptions to our knowledge. By taking into account a social trade-off between targeting the exchange rate and saving on intervention costs, Im (2001) builds an endogenous target zone model of the exchange rate, while Lee (2011) improves the work of Hsieh (1992) to model an endogenous intervention rule of optimizing foreign exchange authority.

This article extends the theoretical works of Im (2001) and Lee (2011) in considering the practical sterilized intervention. We employ a rational expectations model with specifications relating to: (i) the objective function of the government; (ii) balance of payments constraint; (iii) permanent and temporary fundamentals in the foreign exchange market, and (iv) an exchange rate target consistent with the long-term fundamentals. We demonstrate not only why exchange rate dynamics can be captured by a structural threshold model but also how to put the model into an empirical investigation.

[2] The solving technology used by Hsieh (1992) is similar to the technology used by Davig and Leeper (2007).

This article achieves several improvements to the prior empirical works in the present study. First, we derive the expectation formation effect implication of the theoretical model that, relative to a clean float regime, the managed float helps to lower the influences of short-term disturbances on the exchange rate, even in the absence of official intervention. Secondly, the stochastic trend of the exchange rate results from the long-term fundamentals of the foreign exchange market. Third, with a fundamental-consistent target of the exchange rate, stationary official intervention can be feasible. Finally, we provide a two-step procedure which first estimates the trend component in the exchange rate and then explains the nonlinear process of the de-trended exchange rate through estimating the derived structural threshold model. In the estimation process, both the long-term factors and the short-term factors which affect the exchange rate are separately identified.

And lastly, a small open economy, Taiwan — known as a typical managed floater after 1980 — is chosen as a demonstration for applying our procedure. The Central Bank of the Republic of China (Taiwan) has an explicit monetary aggregate target and a concealed exchange rate target. Both are adjustable and needn't be fulfilled as economic and financial conditions are out of the bank's expectations.[3] However, these targets so far seem to help achieve the long-term objectives of the bank and build its reputation. Under conditional openness of financial accounts, the bank autonomously conducts a discretionary monetary policy without causing an "inflation bias" and it adopts an intermediate exchange rate regime which is "viable" well.[4]

[3] For example, due to bolstering economic recovery from global financial turmoil and net foreign capital inflows in the second half of 2009, M2 grew by 7.21 percent, breaching the upper limit of the CBC's 2.5 to 6.5 percent target zone.

[4] The "bipolar view" warns against the room for intermediate exchange rate regime. For instance,

The remainder of this article is organized as follows. An introduction to the theoretical framework of managed float is provided in Section 2. Also presented is the derived endogenous threshold model with optimal official intervention amounts and the nonlinear process of the exchange rate. Section 3 provides an explanation of the estimation strategy adopted for this study along with solutions of certain difficulties arising in the estimation of the structural model. Section 4 gives a brief review of the monetary and foreign exchange policies of Taiwan's central bank. An empirical demonstration of our model using Taiwan's data is carried out in Section 5. Finally, the conclusions drawn from this study and some remarks are provided in Section 6.

2. The structural threshold model with an optimal intervention rule

Rather than assuming an ad hoc intervention rule, this article considers the objective function of the government's exchange rate policy. We define $\mathrm{E}_t x_{t+i} = \mathrm{E}(x_{t+i} \mid \Omega_t)$ as an expectation with regard to x_{t+i} based upon the information set Ω_t up to time t. Assume that the goal of the foreign exchange authority in an open economy is to minimize the social loss function:

$$\mathrm{LOSS} = \mathrm{E}_0 \sum_{t=0}^{\infty} \beta^t \left[\phi (e_t - e_t^*)^2 + (\mathrm{INT}_t)^2 + c d_t \right], \qquad (1)$$

where e_t denotes the endogenous, logarithmic exchange rate, e_t^* represents a pre-announced exchange rate target, INT_t is defined as the net buying of the foreign exchange authority, d_t denotes an official intervention index (in cases where the government intervenes in the exchange rate market, $d_t = 1$; otherwise, $d_t = 0$),

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Eichengreen (1994, pp. 4-5) argues "...contingent policy rules to hit explicit exchange rate targets will no longer be viable in the twenty-first century…[C]ountries...will be forced to choose between floating exchange rates on the one hand and monetary unification on the other."

parameter β refers to the social discount factor, ϕ is the relative weight of the deviation of the exchange rate from its target, and term c represents a fixed cost associated with government intervention in the exchange market.

In the social loss function (1), there is a trade-off between the loss arising from the departure of the exchange rate from its target and the loss from government's adopting intervention operations, which are in line with Ito and Yabu (2007). The latter further contains two parts of intervention costs. The second term in the loss function captures variable costs of the intervention in the foreign exchange market, which are assumed to be increasing with the amount of intervention, irrespective of whether the intervention involves buying or selling (ref. Miller and Zhang, 1996, and Ghosh, 2002). The last term in equation (1) captures fixed costs which are associated with the intervention activities.

Fixed costs may be specified to model the political costs of intervention. In addition, fixed costs are empirically important: if there was no fixed intervention cost, intervention would take place in every business day. Cadenillas and Zapatero (1999) argue that everyday-intervention is inconsistent with the intervention practice of foreign exchange markets and Ito and Yabu (2007) state that Japanese interventions were actually carried out only for less than 10% of the business days on average.

It is recognized that a nation's economic transactions with the rest of the world can be summarized by its 'balance of payments' (BOP), which is defined as the sum of the balance of the current account and the balance of the financial (capital) account. Under a market condition of free adjustment, the foreign exchange rate market clears automatically and BOP = 0. On the other hand, when a market is manipulated by government, it cannot automatically clear and BOP equals the net buying of foreign reserves by the foreign exchange authority, i.e., the amount of government intervention

(INT_t).

Let f_t be a linear combination of fundamental factors having an influence on the foreign exchange market. Following the balance of payments constraint, the exchange rate obeys:

$$f_t + \delta e_t + \gamma(e_t - \mathrm{E}_t e_{t+1}) = \mathrm{INT}_t, \tag{2}$$

where parameter δ captures the price elasticity of the current account and γ is the semi-elasticity of interest in the financial account.

Solving equations (1) and (2) gives the rule for the net buying of foreign reserves under a managed float, as follows:

$$\mathrm{INT}_t = \begin{cases} \dfrac{\phi}{(\delta+\gamma)^2+\phi}\left[f_t + (\delta+\gamma)e_t^* - \gamma \mathrm{E}_t e_{t+1}\right], & \text{if } d_t = 1, \\ 0, & \text{if } d_t = 0, \end{cases} \tag{3}$$

where

$$d_t = \begin{cases} 1, \text{ if } \gamma \mathrm{E}_t e_{t+1} - f_t - (\delta+\gamma)e_t^* \notin \left[-(\delta+\gamma)C,\ (\delta+\gamma)C\right], \\ 0, \text{ if } \gamma \mathrm{E}_t e_{t+1} - f_t - (\delta+\gamma)e_t^* \in \left[-(\delta+\gamma)C,\ (\delta+\gamma)C\right], \end{cases} \tag{4}$$

and $C \equiv \sqrt{\left[(\delta+\gamma)^2+\phi\right]c}/\phi$. Equations (3) and (4) represent the optimal intervention rule of the foreign exchange authority: it intervenes only when the condition of the foreign exchange market is over an endogenous bottom line in which it can be tolerant of.

Based upon equation (3), we can show that the exchange rate under a managed float is:

$$e_t = e_t^i d_t + e_t^n (1 - d_t), \tag{5}$$

where

$$e_t^n = \frac{\gamma \mathrm{E}_t e_{t+1} - f_t}{\delta + \gamma} \tag{6}$$

is the exchange rate at time *t* without government intervention, and the exchange rate with intervention is

$$e_t^i = \alpha e_t^n + (1-\alpha)e_t^*, \tag{7}$$

with $\alpha \equiv (\delta+\gamma)^2/[(\delta+\gamma)^2+\phi]$. The rule for government intervention can be re-written as:

$$d_t = \begin{cases} 1, \text{if } e_t^n - e_t^* \notin [-C, C], \\ 0, \text{if } e_t^n - e_t^* \in [-C, C]. \end{cases} \tag{8}$$

Equation (8) implies the decisions of the foreign exchange authority depend on the market-equilibrium exchange rate's deviation from its time-varying target.

In order to derive an analytical and empirical solution of the exchange rate dynamics, we decompose the fundamentals into two parts: the permanent and temporary portions. The permanent fundamentals of the foreign exchange market (f_t^p) are assumed to be integrated of order one and its difference is assumed to follow an autoregressive process of order *p*, while the temporary fundamental (f_t^t) is assumed to follow a stationary autoregressive process of order *q*. In other words,

$$f_t = f_t^p + f_t^t,$$

where $\Delta f_t^p = \lambda_0^p + \lambda_1^p \Delta f_{t-1}^p + \cdots + \lambda_p^p \Delta f_{t-p}^p + \varepsilon_t^p$, $f_t^t = \lambda_0^t + \lambda_1^t f_{t-1}^t + \cdots + \lambda_q^t f_{t-q}^t + \varepsilon_t^t$, and both ε_t^p and ε_t^t are uncorrelated white noises. In this study, we use the superscript '*p*' and '*t*' to denote permanent and temporary factors, respectively.

For illustrative simplicity, we rewrite Δf_t^p and f_t^t as a VAR (1) process. First, we define $\Delta Z_t^p \equiv (\Delta f_t^p, \Delta f_{t-1}^p, \cdots, \Delta f_{t+1-p}^p)'$, which follows the process:

$$\Delta Z_t^p = A_0^p + A_1^p \Delta Z_{t-1}^p + U_t^p, \tag{9a}$$

where A_0^p is a $p \times 1$ scalar vector with λ_0^p in the first element and zero in others,

A_1^p is the $p \times p$ companion coefficient matrix, and U_t^p is a $p \times 1$ serially-uncorrelated error term vector with ε_t^p in the first element and zero in others. Likewise, with proper definitions of symbols, we have:

$$Z_t^t = A_0^t + A_1^t Z_{t-1}^t + U_t^t. \tag{9b}$$

To obtain the implied empirical model for the exchange rate under managed float, except for the assumption about the process of exogenous variables, one needs a specification of the exchange rate target. Usually a government prefers to choose a relatively stable target level for its exchange rate and intervenes "to smooth excess exchange rate fluctuations that are judged to be clearly out of line with economic fundamentals."(see the survey of Chiu, 2003). For analytical simplification, this article assumes that the government merely sets its expected trend part of the exchange rate as the exchange rate target:

$$e_t^* = c^* - \mathrm{E}_{t-1} \frac{f_t^p}{\delta}, \tag{10}$$

where c^* is the population mean of the error correction term $(e_t^f + f_t^p / \delta)$, with e_t^f as the exchange rate under a clean float. Equation (10) can represent a fundamental-consistent target level, since e_t^* has the same trend as the market equilibrium rate.

Let the term $\rho \equiv \gamma/(\delta + \gamma)$, and define l_n to be the $1 \times n$ unit vector with one as the first element and I_n be the $n \times n$ identity matrix. We solve the exchange rate under a managed float in the absence of intervention as:[5]

[5] The model is solved under a simplified distribution assumption that disturbances follow uniform distribution. An appendix for the details of the derivation of e_t^n and e_t^i is available upon request.

$$e_t^n = -\frac{1}{\delta} f_t^p + \phi_0^n + \phi_1^n \Delta Z_t^p + \phi_2^n Z_t^t, \tag{11}$$

where $\phi_0^n = \rho/(1-\alpha\rho)\left[-l_p(I_p - \alpha\rho A_1^p)^{-1} A_0^p/\delta - l_q(I_q - \alpha\rho A_1^t)^{-1}\alpha\rho A_0^t/\gamma + (1-\alpha)c^*\right]$, $\phi_1^n = -(\rho l_p/\delta)A_1^p(I_p - \alpha\rho A_1^p)^{-1}$, and $\phi_2^n = -(\rho l_q/\gamma)(I_q - \alpha\rho A_1^t)^{-1}$. By substituting equation (11) into (7) we obtain the exchange rate under managed float in the presence of intervention as:

$$e_t^i = -\frac{1}{\delta} f_t^p + \phi_0^i + \phi_1^i \Delta Z_t^p + \phi_2^i Z_t^t + \phi_3^i U_t^p, \tag{12}$$

where $\phi_0^i = (1-\alpha)c^* + \alpha\phi_0^n$, $\phi_1^i = \alpha\phi_1^n$, $\phi_2^i = \alpha\phi_2^n$, and $\phi_3^i = (1-\alpha)l_p/\delta$.

Substituting equations (10)-(12) back into equation (3), it is easy to confirm that the optimal intervention is stationary in the case of a fundamental-consistent target. This guarantees the sustainability of the exchange rate regime of managed float in the long run. In addition, the impact of market fluctuations (in terms of the absolutes of coefficients, ϕ_1^n, ϕ_2^n, ϕ_1^i, and ϕ_2^i) is decreasing in the foreign exchange authority's attitude to the weight of targeting the exchange rate (ϕ). An interesting implication of the managed floating exchange rate regime is as follows: the more the government is concerned about the exchange rate target, the smaller impact the short-run fluctuation of the fundamental has on the exchange rates. Since a clean float corresponds to the extreme case of the lowest ϕ ($\phi = 0$) and of no future regime change under it, the milder influence of the fundamental on the exchange rate under a managed float confirms the existence of Davig and Leeper's (2007) expectation formation effect.

3. The Theoretical-based Exchange Rate Model

A few problems arise when we intend to estimate the structural threshold model. First, the permanent and temporary fundamental indices are generally unobserved and thus the AR coefficients of the fundamentals, A_0^p, A_1^p, A_0^t, A_1^t, cannot be directly

estimated.

Secondly, since e_t, e_t^n, and e_t^i are non-stationary variables, the least squares estimator based upon the observed exchange rate will have non-standard asymptotic distribution and different rates of convergence when applied to the $I(1)$ process. Clearly, a further issue which has to be dealt with in the estimation of the model is how to achieve such stationarity. If we were to take the first difference to achieve stationarity, then this would result in four possible states for subsequent consideration in the objective function, which would thereby complicate the minimization problem. Furthermore, this might also result in the misspecification of the model as a result of ignoring the co-integrating relationship between variables.

Thirdly, the threshold value of the model is ultimately decided by the set of structural parameters; therefore, the objective function is a discontinuous function of the structural parameters (δ, ϕ, γ, c). In a more specific term, the value of the objective function may fluctuate from iteration to iteration within the process of minimization, essentially because the function $d_t = d_t(\delta, \phi, \lambda, c)$ takes on the value of either 0 or 1. The objective function with these characteristics in the present study results in our estimation being non-typical, and thus, renders empirical studies of exchange rates to be relatively difficult. The main difference between our model and the standard threshold model lies in the endogenous threshold value of the former and the exogenous threshold value of the latter.

We propose the following solution to solve the above problems which we confront. In the first step, we formulate a permanent fundamental index and then estimate equations (9a) and (9b). Note that the exchange rate has a stochastic trend both with and without government intervention. By applying Johansen's co-integration test (Johansen and Juselius, 1990) one can test the existence of the co-integration

relation between the exchange rate and related exogenous variables. Note that without knowing the scale of the linear combination of the co-integrating variables, the structure parameter δ cannot be identified in the current stage. Define $\breve{f}_t^{\,p} = -(1/\delta)\, f_t^{\,p}$, thus $\Delta\breve{Z}_t^{\,p} = -(1/\delta)\Delta Z_t^{\,p}$, and

$$\Delta\breve{Z}_t^{\,p} = \breve{A}_0^{\,p} + \breve{A}_1^{\,p}\Delta\breve{Z}_{t-1}^{\,p} + \breve{U}_t^{\,p}, \qquad (9a')$$

where $\breve{A}_0^{\,p} = -A_0^{\,p}/\delta$, $\breve{A}_1^{\,p} = A_1^{\,p}$, and $\breve{U}_t^{\,p} = -U_t^{\,p}/\delta$. Likewise, one can regress the de-trended exchange rate on temporary factors of the foreign exchange market to obtain their linear combination as the single temporary index, $\breve{Z}_t^{\,t}$, where $\breve{Z}_t^{\,t} = \kappa Z_t^{\,t}$, and

$$\breve{Z}_t^{\,t} = \breve{A}_0^{\,t} + \breve{A}_1^{\,t}\breve{Z}_{t-1}^{\,t} + \breve{U}_t^{\,t}, \qquad (9b')$$

with $\breve{A}_0^{\,t} = \kappa A_0^{\,t}$, $\breve{A}_1^{\,t} = A_1^{\,t}$, and $\breve{U}_t^{\,t} = \kappa U_t^{\,t}$.

Therefore, the exchange rate in the absence of government intervention is re-written as:

$$e_t^n = \breve{f}_t^{\,p} + \breve{\phi}_0^{\,n} + \breve{\phi}_1^{\,n}\Delta\breve{Z}_t^{\,p} + \breve{\phi}_2^{\,n}\breve{Z}_t^{\,t}, \qquad (11')$$

with $\breve{\phi}_0^{\,n} = \phi_0^n = \rho/(1-\alpha\rho)\left[l_p(I_p - \alpha\rho\breve{A}_1^{\,p})^{-1}\breve{A}_0^{\,p} - l_q(I_q - \alpha\rho\breve{A}_1^{\,t})^{-1}\alpha\rho\breve{A}_0^{\,t}/\gamma\kappa + (1-\alpha)c^*\right]$,

$\breve{\phi}_1^{\,n} = -\delta\phi_1^n = \rho l_p\breve{A}_1^{\,p}(I_p - \alpha\rho\breve{A}_1^{\,p})^{-1}$, and $\breve{\phi}_2^{\,n} = \phi_2^n/\kappa = -(\rho l_q/\gamma\kappa)(I_q - \alpha\rho\breve{A}_1^{\,t})^{-1}$.

Similarly, the exchange rate in the presence of government intervention is:

$$e_t^i = \breve{f}_t^{\,p} + \breve{\phi}_0^{\,i} + \breve{\phi}_1^{\,i}\Delta\breve{Z}_t^{\,p} + \breve{\phi}_2^{\,i}\breve{Z}_t^{\,t} + \breve{\phi}_3^{\,i}\breve{U}_t^{\,p}, \qquad (12')$$

where $\breve{\phi}_0^{\,i} = (1-\alpha)c^* + \alpha\breve{\phi}_0^{\,n}$, $\breve{\phi}_1^{\,i} = \alpha\breve{\phi}_1^{\,n}$, $\breve{\phi}_2^{\,i} = \alpha\breve{\phi}_2^{\,n}$, and $\breve{\phi}_3^{\,i} = -\delta\phi_3^i = -(1-\alpha)l_p$.

The exchange rate, e_t, has a stochastic trend, $\breve{f}_t^{\,p}$, both with and without government intervention (denoted as e_t^i and e_t^n, respectively). This suggests that de-trended series $\tilde{e}_t = e_t - \breve{f}_t^{\,p}$, $\tilde{e}_t^{\,n} = e_t^n - \breve{f}_t^{\,p}$, and $\tilde{e}_t^{\,i} = e_t^i - \breve{f}_t^{\,p}$ are all stationary.

Substitution of (9a') and (9b') into (11') and (12') gives the de-trended series:

$$\tilde{e}_t^n \equiv e_t^n - \breve{f}_t^p = \psi_0^n + \psi_1^n \Delta \breve{Z}_{t-1}^p + \psi_2^n \breve{Z}_{t-1}^t + v_t^n, \tag{13}$$

$$\tilde{e}_t^i \equiv e_t^i - \breve{f}_t^p = \psi_0^i + \psi_1^i \Delta \breve{Z}_{t-1}^p + \psi_2^i \breve{Z}_{t-1}^t + v_t^i, \tag{14}$$

where $\psi_0^m = \breve{\phi}_0^m + \breve{\phi}_1^m \breve{A}_0^p + \breve{\phi}_2^m \breve{A}_0^t$, $\psi_1^m = \breve{\phi}_1^m \breve{A}_1^p$, $\psi_2^m = \breve{\phi}_2^m \breve{A}_1^t$, with $m = i, n$, $v_t^n = \breve{\phi}_1^n \breve{U}_t^p + \breve{\phi}_2^n \breve{U}_t^t$, and $v_t^i = (\breve{\phi}_1^i + \breve{\phi}_3^i)\breve{U}_t^p + \breve{\phi}_2^i \breve{U}_t^t$.

Based upon the previous analytical results given by equations (13) and (14), we can model the dynamics of the exchange rate using the following threshold model:

$$\tilde{e}_t = \tilde{e}_t^i d_t + \tilde{e}_t^n (1 - d_t) + \xi_t, \tag{15}$$

where ξ_t is a sequence of independent statistical errors, which captures the deviation of the exchange rate from the predicted exchange rate, $\tilde{e}_t^n$ or $\tilde{e}_t^i$, by the theoretical model.

Given the AR coefficients defined in equations (9a') and (9b'), we can go on to estimate the structural parameters based upon:

$$\min_{(\delta,\phi,\gamma,c,\kappa)} \sum_{t=1}^{T} \left\{ \tilde{e}_t - \tilde{e}_t^n \cdot (1 - d_t) - \tilde{e}_t^i \cdot d_t \right\}^2, \tag{16}$$

where

$$d_t = \begin{cases} 1, & \text{if } |\tilde{e}_t^n - \tilde{e}_t^*| > C, \\ 0, & \text{if } |\tilde{e}_t^n - \tilde{e}_t^*| \le C, \end{cases} \tag{8'}$$

with $\tilde{e}_t^* \equiv e_t^* - \breve{f}_t^p$. Therefore, the unknown parameters (δ, ϕ, γ, c, κ) can be estimated by minimizing equation (16), subject to (8'), (13), and (14).

Finally, since the objective function is not differentiable and has many local minimums, we conduct the optimization by the simplex algorithm.[6] In order to make

[6] See Press, Teukolsky, Vetterling, and Flannery (1999) for more details.

sure that the global minimum is obtained we randomly draw one thousand different initial values from the uniform distribution and choose the global minimum from the 1,000 optimizations.

4. The Central Bank of China in Taiwan and its Policies

Our empirical study considers the case of Taiwan as a prime example of a small open economy with a foreign exchange market operating under managed float.

Background

Taiwan's monetary authority, formally the Central Bank of the Republic of China (hereafter the CBC), conducts discretionary monetary policy and dirtily floats its dollar. The CBC has been famous for its policy performance. Comparing standard deviations of many macroeconomic variables with those simulated from more than 60 artificial monetary rules, Cover, Hueng and Yau (2002) conclude that the CBC had been very successful in using discretionary policies for three decades before 2000. Due to the great performance of the monetary policies, the Governor of the CBC, Fai-Nan Perng was awarded the World's Top Central Banker title in 2000, 2005, 2006, 2007, 2008, 2009 and 2010 by *Global Finance*, and the Central Banker of the Year, Asia, in 2009 by *The Banker*.[7]

After WWII, Taiwan was restored from Japanese by people who migrated from Mainland China. Due to a lack of suppliers and serious government deficits, the annual inflation rate rose to 500%-1,200% during 1945-1949 and caused social disorder in Taiwan. In the 1950s and 1960s, the government decided to develop a light industry

[7] Formally, the Governor of the CBC is appointed for a term of five years. Perng has assumed this position since 1998 and to date; he is the only cabinet officer in Taiwan to have passed through political unrest during the ruling party switch from the KMT (Kuomintang) to the DPP (Democratic Progressive Party) opposition party in 2000 and the switch back in 2008.

and switched the development strategy from an "import substitution" to an "export-led" growth.

The CBC resumed its operations in 1961. At that time, Taiwan experienced low income, trade deficits, and a shortage of foreign exchange.[8] According to *The Central Bank of China Act*, the bank's operational objectives include promoting financial stability, ensuring sound banking operations, maintaining the stable internal and external values of the currency and, within the scope of the above three objectives, fostering economic development. To help economic growth and the accumulation of foreign reserves, the CBC kept the real interest rate positive, stipulated a variety of foreign exchange regulations, and pegged the exchange rate of its New Taiwan Dollar (the NT dollar) to the U.S. dollar at an undervalued level. The exchange rate was fixed at 40 during 1960-1972, 38 during 1973-1977, and floated in a range of 36 to 40 during 1978-1986.[9] The CBC also provided export-loan accommodations to banks to promote exports.

Knowing that price stability is fundamental to maintaining sustainable economic growth and by keeping the late 1940s severe inflation experience in mind, the CBC is conservative in issuing money. Thanked to a sound government budget and high economic growth during the 1960s and 1970s, the CBC's independent role in setting monetary policies was not changed, even though in 1979 the revised *Central Bank of China Act* put the CBC under the jurisdiction of the Executive Yuan, instead of the

[8] According to the CBC Act, the issuance of the NT dollar currency must be backed by gold and foreign exchange reserves. In practice, the NT dollar value of foreign exchange reserves held by the CBC always far exceeds the amount of currency issued.

[9] There had been a multiple exchange rate system in the 1950s in Taiwan.

Office of the President, and made the CBC accountable to the Congress.[10]

Along with rapid financial developments, improving productivity, and low valued currency, Taiwan's open degree and trade surplus rapidly increased.[11] The open degree in terms of exports to GDP ratio plus imports to GDP ratio rose from 24% in the 1950s, 42% in the 1960s, 88% in the 1970s, to 96% in the 1980s. The high openness makes Taiwan more vulnerable to external shocks. At the same time, the small country accumulated plenty of foreign assets through the surplus of its balance of payments and its foreign reserves turned to be the world's number one in 1991.[12] The huge trade surplus, especially from the U.S. market, finally resulted in appreciation pressure on the NT dollar and a series of policy reforms in Taiwan.[13]

In the 1980s, the CBC speeded up a sequence of financial liberalizations and internationalization, with a large-scale relaxation of its foreign exchange regulations in 1987. Major reforms included: increasing exchange rate flexibility, lifting limits on foreign exchange positions, developing foreign exchange derivatives markets, and removes regulation on capital movement. Facing a surge of capital inflows, the CBC insisted on a policy of gradual appreciation to enable exporters to adjust for the impact

[10] Taiwan had government budget surplus in the 1960s and 1980s. Although there were some distinct deficits in the 1970s with two oil price shocks, the overall government budget was nearly balanced during 1960-1990, see Lin, Lee and Huang (1996).

[11] Taiwan had become a middle-income country in 1980. In the beginning of 2011, its per capita GDP was over US$20,000 for the first time.

[12] Taiwan's foreign reserves have been the largest in terms of per capita aggregates since 1983.

[13] According to the Plaza Accord of the five industrial countries meeting, Asian currencies began to appreciate. To one U.S. dollar, the exchange rate of the NT dollar rose from 40 in 1985 to 25 in 1992, the Japanese Yen rose from 239 in 1985 to 138 in 1989 and to 94 in 1995, the Korean Won rose from 870 in 1985 to 671 in 1989, while the Singapore dollar rose from 2.2 in 1985 to 1.7 in 1991.

of a rising NT dollar. To alleviate the effect of the huge balance of payment surplus on the reserve money, since the end of 1988, the CBC also increased the discount rate and reserve requirements, issued negotiable certificates of deposit, and exercised selective credit controls. Even though the M2/GDP eventually rose from 72% in 1982 to 149% in 1991, the CPI inflation rose only from 3.0% to 3.6%, with an average of 1.9% in 1982-1991, while the rate of economic growth rose from 4.0% to 7.9%, with an average of 7.8%.

Prior to February 1979, management of foreign exchange in Taiwan was characterized by a central clearing and settlement system. Following the establishment of the Taipei Foreign Exchange Market in February 1979, a managed float exchange rate system was formally implemented.[14] The CBC announced "…the NT dollar exchange rate has been determined by the market. However, when the market is disrupted by seasonal or irregular factors, the Bank will step in." It intervened intensively to keep sharp appreciation of the NT dollar and sterilized the purchasing of the U.S. dollar in the 1980s and the early 1990s. The CBC abolished the central rate system in 1989 and the NT$/US$ rate began to move more freely according to market conditions.

Except for the Plaza Accord on the NT dollar exchange rate, another strict test of Taiwan's managed floating regime was the 1997-1998 Asian financial crisis. The CBC only defended its currency from July to October 1997. As a result of heavy intervention, the foreign exchange reserves fell by US$7 billion within four months. At

[14] At the beginning of managed floating, daily fluctuations in the inter-bank rate of the foreign exchange were limited to upper and lower bounds around a central rate, which was the weighted average inter-bank rate of the previous business day, and the counter rate for small-amount trading was set within a narrow band around the central rate.

the same time, monetary conditions tightened, interest rates went up and stock prices fell sharply. As the Asian financial crisis showed no signs of abating, in mid-October 1997, the CBC ceased to defend the exchange rate, and at the time lowered the required reserve ratios. The NT dollar depreciated sharply from 28.6 in September to 31.6 in November, and further depreciated to 33.9 in January 1998. In addition to implementing a flexible exchange rate policy, the CBC fended off speculative attacks in the foreign exchange market by prohibiting domestic institutional investors from engaging in non-delivery forward transactions to block the speculators' access to NT dollar funds. Therefore, the downward pressure on the NT dollar was largely relieved, and the exchange rate no more depreciated.

The cross-strait tensions in the middle 1990s and the bursting of the global IT bubble in early 2000s, similar to the Asian financial crisis, were challenges to Taiwan's financial stability. The CBC responded by open market operations, reformed the reserve requirement system, modernized payment systems, and furthered the deregulation of financial account transactions, such as lifting more restrictions on the foreign portfolio investments in Taiwan and allowing for new foreign exchange derivatives to be introduced into the market and offshore banking units to expand their lines of business. On the other hand, since the outbreak of the Asian financial crisis in 1997, the CBC has strengthened the real-time reporting system for large-value foreign exchange transactions.

Recently, the worldwide financial turmoil in late 2008 and early 2009 severely impacted Taiwan's economy. The economic growth rate turned to be -1.9% and unemployment rate rose to nearly 6%. Both are historic extreme values in Taiwan's 60-year development. To boost domestic demand, the CBC lowered policy rates seven times during September 2008 and February 2009, as the inflationary pressure remained

largely subdued. In addition, the CBC engaged in open market operations to keep reserve money and the inter-bank call-loan rate at accommodative levels and continued with financial liberalization. New foreign exchange products were introduced and cross-border remittances were further deregulated. Taiwan's economy has regained momentum since the fourth quarter of 2009.

Monetary policy

The CBC believes that price stability is a fundamental key to economic growth. It conducts open market operations nearly every business day, along with infrequent required reserve adjustments, discount window lending, redeposit system adjustments, liquidity requirement system adjustments, moral suasion, as well as by issuing selective preferential loans and credit controls.

Since the mid-1980s, the CBC chose monetary aggregates to be the intermediate target and reserve money to be the operating target. Due to instable relations between M1B and GDP, the bank then formally chose to target the M2 to GDP ratio as the intermediate target and announced it periodically since 1992.[15] In practice, the CBC adopts a framework where it periodically checks whether its operating target, reserve money, has been achieved in the short run, and in turn measures an intermediate target to assess how effectively monetary policy is being transmitted to achieve its final policy objectives, i.e., price stability, financial soundness, and economic growth.

According to the policy document of the CBC in 2006, to accommodate rapidly changing economic and financial conditions, the CBC not only relies on numerical targets for money and credit but also uses a wide range of economic and financial indicators in the formulation and implementation of monetary policy. The economic

[15] In Taiwan, M1B includes M1A (currency held by the public plus checking accounts plus passbook deposits) and passbook saving deposits. M2 equals M1B plus quasi money.

indicators include exports, imports, industrial production and the rate of inflation, unemployment, economic growth, etc. The financial indicators include interest rates at different maturities, exchange rates, excess reserves, bank deposits and credit, and the balance of payments.[16] Moreover, "due to increasing external influence on the Taiwan economy, the CBC usually takes monetary policy adjustments in other countries into consideration when formulating its own policy" (Central Bank of China, 2006, p.16).

Some researchers argue that the CBC often missed its monetary aggregate targets and that targeting monetary aggregates were not popular anymore in main countries. They thus suggest employing "open economy's monetary rules" to describe the CBC's monetary policy and are partially right. The fact is that: the CBC conducts a discretionary monetary policy and takes into account many factors including those in the international dimension to formulate and implement its monetary policies.[17] Although the CBC's monetary policies are highly flexible and not easily described, it appears to work well. Hou (2010) calculates both the "monetary aggregate target achievement rate" in terms of a proportion of years within the target zone and the corresponding inflation rate in Taiwan and Western G6 plus Australia and Switzerland. He finds the achievement rate for Taiwan is 61.6%, only lower than Canada and the U.S., but Taiwan has the lowest inflation rate among the nine countries.[18]

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[16] The CBC has implicitly incorporated interest rate targeting in its framework of monetary policies (see, Yang and Shea, 2006, p.388).

[17] The estimation by Ho and Lin (2006) shows that the CBC mainly targeted the exchange rate in 1982-1991 and switched to target the inflation rate after 1991. The empirical findings of Taiwan by Chen and Wu (2010) suggest that a money growth rule is more appropriate to describe the monetary policy reaction from 1981-1997, while an interest rate rule seems to have a better fit for the period from 1998-2008.

[18] Hou (2010, fn.23) also noted that real side disturbances are more important than financial

Foreign exchange policies

The openness degree in terms of the ratio of exports plus imports to GDP is high in Taiwan. It has been higher than 80% since 1973 and over 100% from 2003 on. Keeping an external price stable is the essential goal of the CBC and a precondition for financial stability and expert-led growth, which are also the final objectives. In Taiwan's case, price stability is a social consensus and the conduct of the foreign exchange policy can't hinder the implement of its monetary policy. For example, the CBC gave up defending the NT dollar during the 1997 Asian financial crisis as the monetary condition became dramatically tight, and tolerated the unpleasant appreciation of the NT dollar following the 2010 Japanese Yen and Renminbi's appreciation as rising prices became a concern. Yang and Shea (2006, p.389-390), in which Shea was the former Deputy Governor of the CBC, state that the CBC has in mind a strategy of repressing the NT dollar to promote exports, yet it is more willing to let the NT dollar appreciate when there is an unendurable inflation pressure. Because the CBC does not want to relax the autonomy of its monetary policy, it has to seek a balance between exchange rate stability and international capital mobility.

Since July, 1987, the CBC has actively deregulated the foreign exchange controls on capital movements. In the mid 2000s, the main regulation is for short-term capital movements that exceed the annual remittance limit on an accumulated basis, with prior approval from the CBC being required. On the other hand, to enhance the surveillance over the foreign exchange market, the CBC developed the Foreign Exchange Declaration System in 1987 and the Reporting System of Foreign Exchange Transactions in 1997. Even increasing the capital mobility is a given principle of the

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disturbances in Taiwan. His simulation results confirm that, relative to interest rate controls, monetary aggregate controls lead to smoother economic growth and stable prices as implied by economic theory.

Taiwan government, the CBC always reserves overall openness in the foreign exchange market. The IMF Staff Position Note: *Capital Inflows: the Role of Controls* by Ostry et al. (2010) which suggests regulations on short-term capital inflows for emerging market economies is most welcome by the CBC for justifying its regulation on items of financial accounts.

A managed floating exchange rate regime neither assures the autonomy of its monetary policy nor adds credit to its maintaining price stability. On the one hand, the CBC has adopted a series of liberalization measures to help broaden and deepen the foreign exchange market. On the other hand, the CBC intervenes in the market whenever it thinks it's necessary and feasible to moderate excessive volatility in the NT dollar exchange rate and monitors foreign exchange market activities closely.

The CBC's exchange rate policy is more discretionary than its monetary policy.[19] The target of the exchange rate is confidential, and the timing, amount, and even the presence and absence of intervention operations are kept secret. Due to the intended vagueness of the CBC's announcement, it is common to see the bank issue press releases to clarify media reports after its announcements. Nonetheless, the relatively large foreign exchange reserves held by the CBC and the success of the CBC in past inflation history appears to build the reputation on the value of the NT dollar.[20]

5. An Empirical Example－Taiwan 1981Q3-2008Q3

[19] Basically, the CBC improves its transparency and communication of monetary policy, only if the increase in transparency does not violate the KISS (keep it simple stupid) principle. However, for the exchange rate policy, the CBC customarily employs a "just do it" approach and occasionally gives ambiguous announcements (Chen and Wu, 2008).

[20] The CBC gives priority to liquidity and safety over profitability when managing foreign reserves. Most of the foreign exchange reserves are invested in government bonds issued by major industrialized countries or deposited in foreign banks of high credit standing.

Our empirical study considers the case of Taiwan as a prime example of a small open economy with a foreign exchange market operating under managed float. Before 1980 Taiwan is characterized by rigid regulation and tight control of its financial market; we therefore gather data after 1981 for analysis (Wen, 2001). Taiwan's quarterly data runs from 1981Q3 to 2008Q3, providing a total of 109 observations. The variables on Taiwan are obtained from *The Financial Statistics Monthly* by the Central Bank of the R.O.C. and the *Quarterly National Income Statistics in the Taiwan Area*, *the Republic of China* by the Directorate-General of Budget, Accounting and Statistics, Executive Yuan, R.O.C. The foreign variables for this study are taken from the Internal Monetary Fund (IFS database).

According to international finance textbooks, the fundamental variables considered here include the differential of the domestic interest rate and the world interest rate, domestic price level, domestic output, and the world output, while the endogenous exchange rate is measured as per US dollar's domestic dollar price. This article uses the New Taiwan (NT) dollar price of the U.S. dollar as the exchange rate (lnTWe). It also uses the Taiwan's interbank overnight rate as the domestic interest rate (TWi), the London Interbank Offer Rate on the US dollar deposits as the world interest rate (60ldd), and the interest rate differential between TWi and 60ldd is defined as (Di). The seasonal-adjusted Taiwan's consumer price index (CPI) is used as domestic price level (lnTWp). The seasonal-adjusted Taiwan's real GDP is used as domestic output (lnTWy). And the U.S. real GDP is used as world output (ln99b_r). In addition, all of the variables are in logarithmic form with the exception of interest rates and their differential.

We first carry out the augmented Dickey-Fuller (ADF) unit root tests on each variable. As presented in Table 1, the results of which show that none of these variables

are rejected by the unit root test statistics at the 5% level of significance, except for the interest rate differential, Di. Therefore, it seems reasonable to use Taiwan's CPI (TWp), Taiwan's output (TWy), and the U.S. output (ln99b_r) to construct the permanent portion of Taiwan's foreign exchange market fundamentals ($\breve{f}_t^p$), but to use the interest rate differential (Di) as the temporary portion of the fundamentals ($\breve{f}_t^t$).

For our purpose in this study, we further apply Johansen's co-integration analysis for confirming the selection of the permanent fundamental variables. Four variables, including the exchange rate, domestic price, domestic output, and foreign output, are considered in our analysis. Based upon the results of the Johansen's maximum eigenvalue test, we are able to reject the null hypothesis of no co-integration, but we are unable to reject the null hypothesis of one co-integrating relationship, at most, at the 5% level of significance according to the statistic.[21]

Given the existence of a co-integrating relationship between the exchange rate and fundamentals, we can now apply the Engle-Granger's single-equation approach to estimate the co-integrating vector. The results of the estimation are presented in Table 2. The evidence of a long-run relationship indicates that an increase in domestic price and the world output have a positive effect on the exchange rate, or the equivalent, which would be a devaluation of the NT dollar. On the other hand, a higher domestic output will subsequently lead to a reduction in the exchange rate, or a corresponding appreciation in the value of the NT dollar. All of the findings are consistent with the theoretical predictions of international finance textbooks.

We then employ the co-integrating vector for constructing the fundamentals of the

[21] The use of one lag length is suggested for the Johansen test in the commonly used HQ and SIC. The Johansen's maximum eigenvalue test statistic is 20.106 which is less than 5% of its critical value.

exchange rate, $\breve{Z}_t^p$. After that, we difference the fundamental variable and fit it by an AR model. Likewise, the AR model of the short-run fundamental (interest rate differential), $\breve{Z}_t^t$, is estimated. Both the lag lengths selected for $\Delta\breve{Z}_t^p$ and $\breve{Z}_t^t$ are ones based on HQ (Hannan and Quinn, 1979) and SIC (Schwarz, 1978).

Once the estimates for the matrices $\breve{A}_0^p$, $\breve{A}_1^p$, $\breve{A}_0^t$, $\breve{A}_1^t$ are obtained, we may link the theoretical model to the econometric model and then estimate the structure parameters by minimizing equation (16) subject to the constraint given in (8'). The objective function of the structural threshold model is not differentiable and has many local minimums. This article conducts the optimization by the simplex algorithm. To make sure that the global minimum is obtained, we randomly draw 1,000 different initial values from the uniform distribution.[22] The global minimum is achieved as the minimum value among the 1,000 optimizations.

Noting that the statistical property of the estimates for the endogenous threshold model is not established in literature, we use the bootstrapped method to construct the confidence interval. The 95% confidence intervals (C.I.) are computed based on 1,000 bootstrapped samples. The estimated results are summarized in Table 3. All of the coefficients are significant at the 5% level.

As Table 3 lists, the estimated elasticity of the relative price between the domestic product and the foreign counterpart is 1.150, a value very close to the unit value. The estimated semi-elasticity of the interest rate differential is 3.067, which is higher than the price elasticity but definitely not a large value. The finding indicates an imperfect mobility of cross-border capital for Taiwan and justifies the feasibility of its central

[22] Moreover, once convergence is achieved, the simplex iteration is restarted again using the converged results as the initial value.

bank's intervention and sterilization policies. The estimated weight of the importance for targeting the exchange rate relative to the intervention cost is very significant (53.547) and reflects the central bank's consideration for stabilizing exchange rates. On the other hand, the fixed intervention cost estimated is 0.051. Although the estimated parameter is a small number, a comparison of itself with the average departure loss from the bank's chasing its exchange rate target (the average of $\phi(e_t - e_t^*)^2$ in the loss function is 0.052) indicates that intervention costs are important to Taiwan's central bank.

Given a significant intervention cost, we expected the Central Bank of Taiwan not to intervene frequently. The average intervention index during the sample period of 107 effective quarters is 0.24, which means a chance of the presence of government intervention is 22%. Since the adoption of a managed float itself lowers the impact of short-term disturbances on the exchange rate, Taiwan's central bank uses oral rather than actual intervention. The bank continues to remind people that Taiwan's foreign exchange market is under a managed float and that the government may step into the foreign exchange market whenever it perceives intervention is necessary. However, the central bank does not need to actually intervene to affect market expectations.

Figure 1 gives our model prediction for government intervention over the period 1982Q1 to 2008Q3. The real line in the figure is the estimated deviation between the exchange rate in the absence of intervention and its target. The dotted line is the estimated intervention threshold while the shaded area in the figure corresponds to the periods for which an official intervention is identified. At first glance, there are three intensive intervention periods in Taiwan's foreign exchange market. First, Taiwan's central bank intervened relatively intensively during the early age of its adoption of a managed floating exchange rate regime in the early 1980s. The second period of

relatively intensive intervention corresponded to the Plaza Agreement of September 1985 that Taiwan's central bank began the succession of currency revaluations under the pressure of the U.S. trade protectionists. The third notable period of official intervention corresponded with the 1997 Asian Financial Crisis. The bank stepped into the foreign market more often after the crisis, until the beginning of 2006. Findings from our empirical investigation are consistent with Taiwan's intervention practices.

6. Conclusions and Remarks

Official intervention is commonplace and there is no appearance of the "disappearing middle" – a hypothesis that there is no room for intermediate exchange rate regimes to survive.[23] By considering a social trade-off between targeting the exchange rate and minimizing official intervention costs subject to the balance of payments constraint, this article demonstrates how nonlinear exchange rate dynamics can be captured by a structural threshold model and how to estimate the model. In line with Leeper and Davig's (2007) "expectation formation effect," official intervention with a fundamental-consistent exchange rate target lowers the influences of short-term disturbances on the exchange rate. In addition, the model also implies that under a fundamental-consistent exchange rate target, intervention for stabilizing exchange rates is feasible. This justifies the official choice of an intermediate exchange rate regime.

This article proposes a two-step procedure for the estimation of the structural threshold model. First, the Johansen co-integration analysis is used to examine the long-run relationships between the exchange rate and the permanent portion of the fundamental variables. The second step involves the estimation of the structural

[23] Studies of Masson (2001), Aizenman (2010), Hossain (2011), and Lee and Chang (2011) show no global trend for the intermediate exchange rate regimes to fade out.

threshold model using the de-trended exchange rate and the short-term fundamentals. This article's estimation strategy achieves in identifying not only the long-term trends in the exchange rate but also the short-term fluctuations of the exchange rate.

This article provides a demonstration of our approach to 1981Q3-2008Q3 Taiwan data. According to our empirical results from estimating Taiwan's exchange rates, the influences of foreign market fundamentals on the exchange rate are consistent with the theory predictions of international finance. Other findings from estimated structural parameters for Taiwan include imperfect capital mobility, the government's significant consideration for the exchange rate target, and important costs of official interventions. Moreover, the endogenous threshold fits Taiwan's intervention practices well by capturing several important periods of official intensive interventions.

There are also several remarks. First, although our analysis is successful in explaining the nonlinearity of the exchange rate, the model is a partial equilibrium model. How to improve the completeness of a macroeconomic model while keeping the analytical simplification and the model's empirical usefulness deserves more research.

Second, it is important for the stochastic trend in the exchange rate to be determined according to the long-run relationship between the economic variables in the model estimation as this article does. One of the potential defects of naively differencing data in many empirical works is that greater insights into the economic model are removed.

Third, empirically there may also be other important fundamentals for the exchange rate dynamics other than this article uses. We suggest considering as many as possible, and then exclude insignificant variables in the estimation of the two steps and do a re-estimation. However, the choice of fundamental variables must be consistent

with the theories. An addition of money supply to the fundamentals after taking into account the effects of price level, output, and the interest rate on the exchange rate appears to be redundant. The variables related to the exchange rate determination depend on which economy is under investigation and which theory the researcher adopts.

Finally, some discussants question that our model is applied to only explain regular interventions instead of interventions for fighting speculative attacks. The model implies that, when a departure of the exchange rate from its target is large enough, a government always intervenes to pin down the exchange rate. The implication seems inconsistent with a government's abandonment of the intervention operations under a crisis. What we are doing in this article is explaining the regular time-series characteristic of the exchange rate through considering an intermediate exchange regime. Official intervention with exchange-rate regime collapsing under speculative attacks is another important issue which will require further study.

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Table 1 ADF unit root tests of variables

Variables	t statistics	One-sided P value
Exchange rate (lnTWe)	-1.404	0.578
Domestic price (lnTWp)	-0.473	0.891
Domestic output (lnTWy)	-2.582	0.100
Domestic interest rate (TWi)	-2.858	0.054
Foreign output (ln99b_r)	-2.401	0.144
Foreign interest rate (60ldd)	-2.315	0.169
Interest rate differential (Di)	3.358*	0.015

Notes: * indicates significance at the 5% level. Lag lengths are selected based on SIC and HQ.

Table 2 Estimation of the long-run relationship between the exchange rate and its fundamentals

Variables	Coefficients	t statistics
Constant term	-25.443*	-17.018
Domestic price (lnTWp)	1.942*	11.577
Domestic output (lnTWy)	-2.421*	-22.368
World output (ln99b_r)	3.460*	20.523

Note: * indicates significance at the 5% level.

Table 3 Estimated structural parameters and their 95% C.I.s

Parameters	Estimates	Lower bound	Upper bound
δ	1.150*	0.909	1.326
ϕ	53.547*	52.598	54.555
γ	3.067*	2.075	4.102
c	0.051*	0.027	0.073
κ	0.576*	0.369	0.783

Note: * indicates significance at the 5% level.

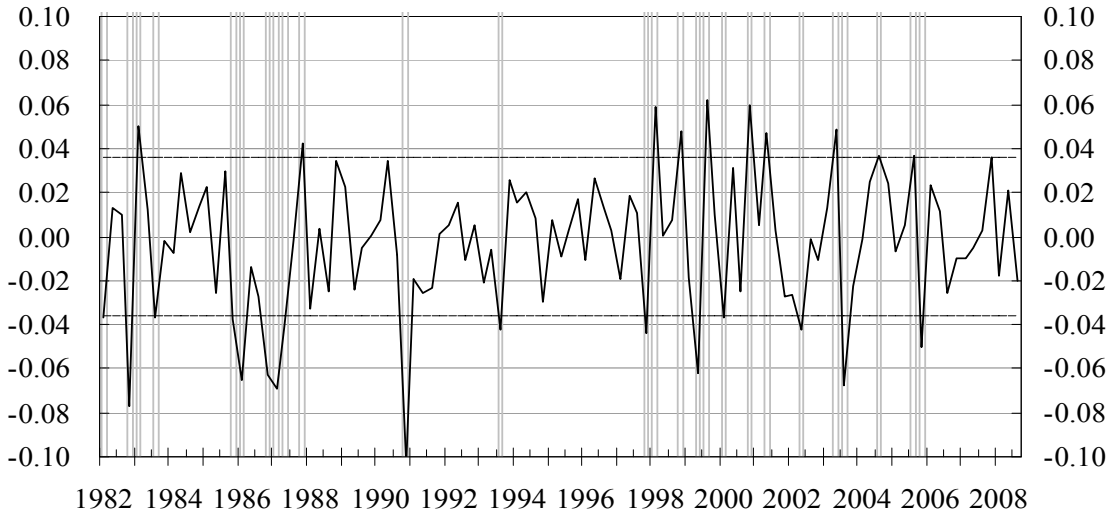

Figure 1 The estimated $e_t^n - e_t^*$ and the intervention threshold