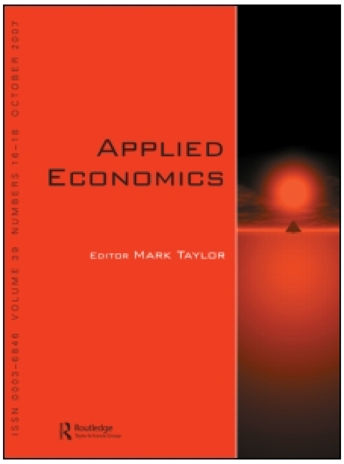

Applied Economics
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713684000

Reserve accumulation and monetary sterilization in Singapore and Taiwan

Alice Y. Ouyang[a]; Ramkishen S. Rajan[b]
[a] China Academy of Public Finance and Public Policy, Central University of Finance and Economics, Beijing 100081, China [b] School of Public Policy, George Mason University, Arlington, VA, USA

First published on: 15 December 2009

To cite this Article Ouyang, Alice Y. and Rajan, Ramkishen S.(2011) 'Reserve accumulation and monetary sterilization in Singapore and Taiwan', Applied Economics, 43: 16, 2015 — 2031, First published on: 15 December 2009 (iFirst)
To link to this Article: DOI: 10.1080/00036840902984373
URL: http://dx.doi.org/10.1080/00036840902984373

Applied Economics, 2011, **43**, 2015–2031

Routledge
Taylor & Francis Group

Reserve accumulation and monetary sterilization in Singapore and Taiwan

Alice Y. Ouyang[a,]* and Ramkishen S. Rajan[b]

[a]*China Academy of Public Finance and Public Policy, Central University of Finance and Economics, Beijing 100081, China*
[b]*School of Public Policy, George Mason University, Arlington, VA, USA*

Asian economies have embraced the globalization of production, trade and capital flows. One dimension of contemporary globalization has been the heavy exchange rate management by, and rapid and massive stockpiling of, foreign exchange reserves in Asia. This article undertakes an empirical investigation to assess the extent of *de facto* sterilization and capital mobility in Singapore and Taiwan using quarterly data between 1990 and 2008. Our empirical results suggest that, since, 2001 both Singapore and Taiwan have a high degree of – but not perfect – *de facto* capital mobility. To date, this high-effective capital mobility has not undermined the ability of the central bank in either economies to sterilize their respective foreign exchange intervention but may make the process increasingly difficult over time.

I. Introduction

Asian economies have embraced the globalization of production, trade and capital flows. One dimension of contemporary globalization has been the rapid and massive stockpiling of foreign exchange reserves in Asia (Fig. 1). By the end of 2008, the region held US$ 4.3 trillion of reserves or over three-fifths of global reserves. In view of the fact that half of Asia's reserves have been attributable to Japan and China, most attention has inevitably been focused on these two Asian giants along with Korea and India. However, it is not often recognized that two smaller economies, namely Singapore and Taiwan, hold over US$ 450 billion of reserves in aggregate (Fig. 2). Indeed, on a per capita basis these two economies are probably the world's two largest reserve holders.[1] Despite this, scant attention has been paid to the rationale for and impact of reserve accumulation in these two economies.

Singapore and Taiwan share many things in common. Both are small and open middle income economies dependent of the global electronic cycles. Both were impacted indirectly by the crisis in 1997 which hit Thailand, Indonesia, Malaysia and Korea, resulting in nominal depreciations of their respective currencies against the US dollar over the period of 1998.[2] Both economies operate managed floats. More to the point, the Monetary Authority of Singapore (MAS) officially manages its currency

*Corresponding author. E-mail: Alice.Ouyang@gmail.com

[1] Apart from the four economies noted above, Korea, India and Hong Kong also hold over US$ 150 billion of reserves each.
[2] Indeed, Taiwan allowed its currency to float in 17 October 1998, leading to a depreciation of the New Taiwan Dollar (NTD). It was against this backdrop that the Singapore dollar was allowed to float during the midst of the crisis. Both currencies lost around 20% of their value *vis-à-vis* the US dollar by the end of 1998. The devaluation of the NTD appeared to trigger the intense speculative pressures against the Hong Kong dollar (Rajan *et al.*, 2002).

Applied Economics ISSN 0003–6846 print/ISSN 1466–4283 online © 2011 Taylor & Francis
http://www.informaworld.com
DOI: 10.1080/00036840902984373

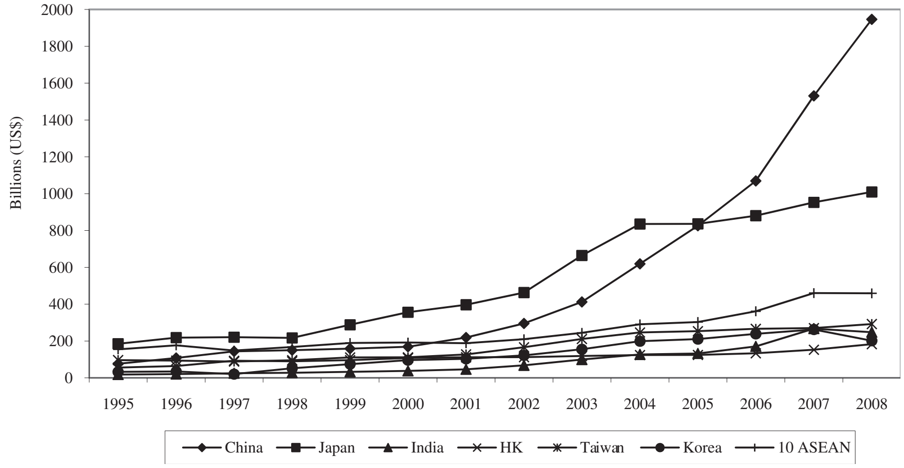

Fig. 1. International reserve holdings in emerging Asia, 1995–2008
Source: All data are from IFS, except Taiwan's data which is from the official website of Taiwan's Central Bank.
Note: Reserves include gold.

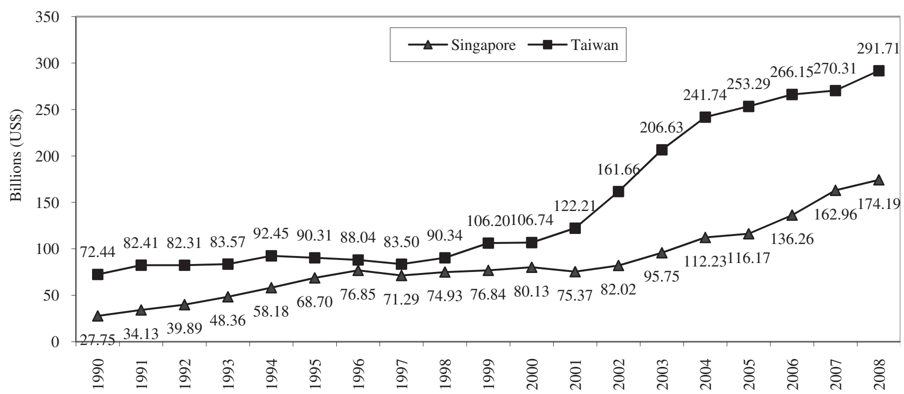

Fig. 2. Reserve growth in Taiwan and Singapore, 1990–2008
Source: The data for Taiwan is from Taiwan Central Bank's official website, while Singapore's data is from IFS.

against a basket of currencies, with the trade-weighted exchange rate used as an intermediate target to ensure the inflation target is attained. Empirical evidence confirms the consistency between *de jure* and *de facto* classification (for instance, see Khor *et al*., 2004; Cavoli and Rajan, 2009, Ch. 3). While Taiwan's Central Bank (the Central Bank of China (CBC)) claims that it operates a flexible exchange rate regime, they add the caveat that the NTD exchange rate 'has been determined by the market. However, when the market is disrupted by seasonal or irregular factors, the Bank will step in' (cited in Cavoli and Rajan, 2009, Ch. 1). There is empirical evidence to suggest that Taiwan also operates a managed float *de facto*, with regular foreign exchange intervention (see Cavoli and Rajan, 2009, Ch. 1 and references cited within). The sustained build-up of reserves suggests that intervention is largely asymmetric in that it stems largely from a desire to maintain relatively stable and/or 'ultra-competitive' exchange rates (Pontines and Rajan, 2008).

Persistent reserve accumulation could run the serious risk of generating increases in inflation in the intervening countries. Accordingly, central banks in Asia have consciously attempted to offset the domestic monetary effects of reserve accumulation. To what extent has this happened in Singapore and Taiwan and how successful have they been thus far in such monetary sterilization activities? To answer these questions, this article examines the causes and monetary consequences of reserve accretion in Singapore and Taiwan since 1990.

The remainder of this article is organized as follows. Section II provides an overview of the sources of reserve accumulation in the two economies, focusing on the balance of payments dynamics between 1990 and 2008. The section also offers evidence of the monetary effects of the reserve accretion in the two economies. Section III outlines a set of simultaneous equations to examine the feedback effects between Net Domestic Assets (NDAs) and Net Foreign Assets (NFAs) as a means of estimating the extent of *de facto* sterilization (sterilization coefficient) and capital mobility (offset coefficient) concurrently. The theoretical foundations of the equations to be estimated are based on a modified version of a model originally outlined by Brissimis–Gibson–Tsakalotos (BGT) (2002). Section IV details the data and definitions of variables to be used in the empirics. Particular attention is paid to the estimation of NFA and NDA. Section V discusses the empirical results of the sterilization and offset coefficients based on quarterly data for the period 1990:Q1 to 2008:Q4 in both cases. We also consider recursive estimates to capture any changes in the magnitude of sterilization over time. Section VI concludes this article. The Appendix offers a brief derivation of the BGT model used in Section III.

II. Reserve Build-up and Monetary Policy Operations in Singapore and Taiwan

Evolution of balance of payments in Singapore

Figure 3 summarizes the dynamics of Singapore's balance of payments between 1990 and 2008. The Singapore dollar has fluctuated somewhat *vis-à-vis* the US dollar, with a persistent appreciation during pre-1997 followed by a one-time depreciation in 1997/98 and relative stability after that. Reserves grew persistently throughout the 15 years with the exception of the recession years of 2001/02 and have been particularly marked between 2002 and 2008. Singapore's foreign reserves reached a high of US$175 billion by the end of 2008. Figures 3 and 4 reveal that Singapore's balance of payments surplus during this period has been due to the large and increasing current account surplus as well as rising Foreign Direct Investment (FDI) inflows. This surplus in the so-called basic balance (i.e. current account plus FDI) has been offset partly by large outflows of portfolio investment and other investments (this category includes the flows between the banking sectors as well as other nonbank sectors and their foreign counterparts including the Asian dollar market).

Figure 5 makes apparent that reserve accumulation and net domestic credit growth are negatively correlated such that the monetary base has remained fairly stable. Inflation has been well-controlled below 3% until mid-2007 but spiked temporarily due to the global commodity price shock (Fig. 6).

Evolution of Taiwan's balance of payments

Figure 7 summarizes the dynamics of Taiwan's balance of payments between 1990 and 2008. For a decade between 1987 and 1997, the NTD and Taiwan's international reserves both remained quite stable. However, since then Taiwan's reserves have been rising, especially since 2001. The overall surpluses on the balance of payments were largely due to current account surpluses, though the economy ran capital account surpluses in a few interim years. Taiwan's balance of payments began to decline after 2004 due to the worsening in the economy's capital account, driven largely by continued investment bank outflows and a surge in portfolio outflows

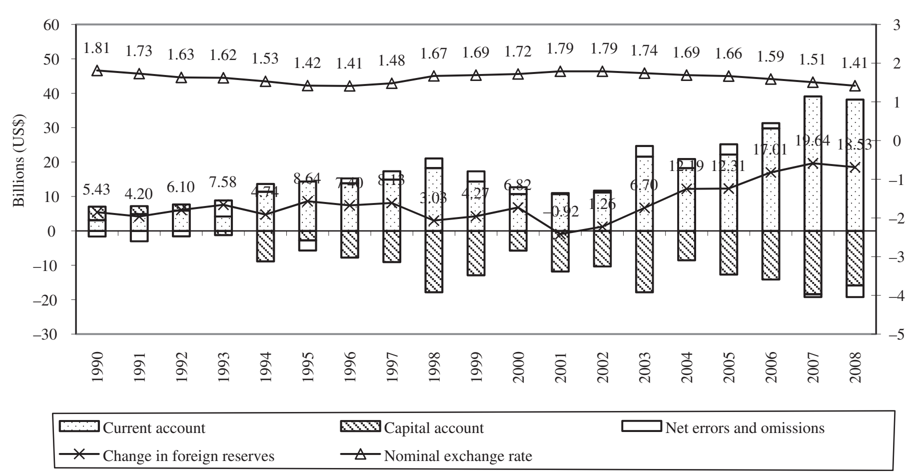

Fig. 3. Trends in Singapore's balance of payments transactions, 1990–2008
Source: All the data are from IFS, except the data for 2008, which are taken from Ministry of Trade and Industry in Singapore.

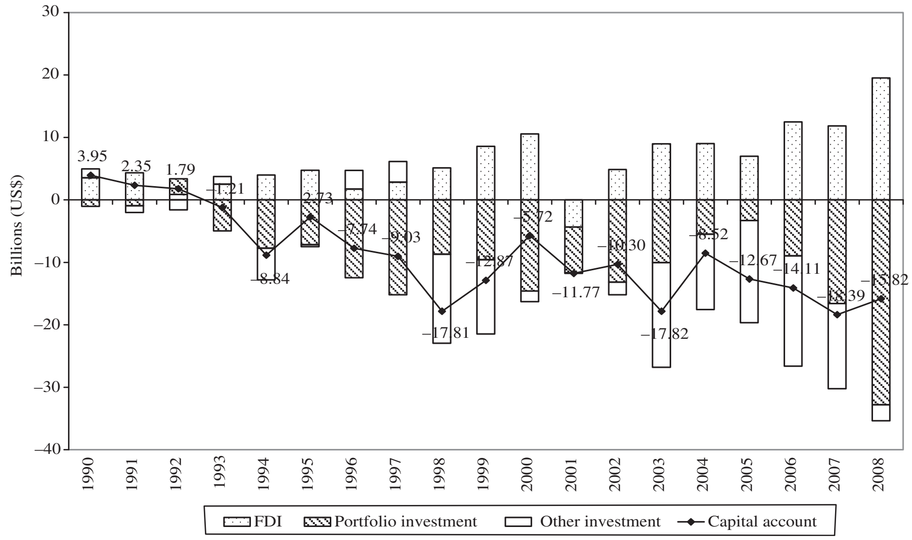

Fig. 4. Capital account components in Singapore, 1990–2008
Source: All the data are from IFS, except the data for 2008 are taken from Ministry of Trade and Industry in Singapore.

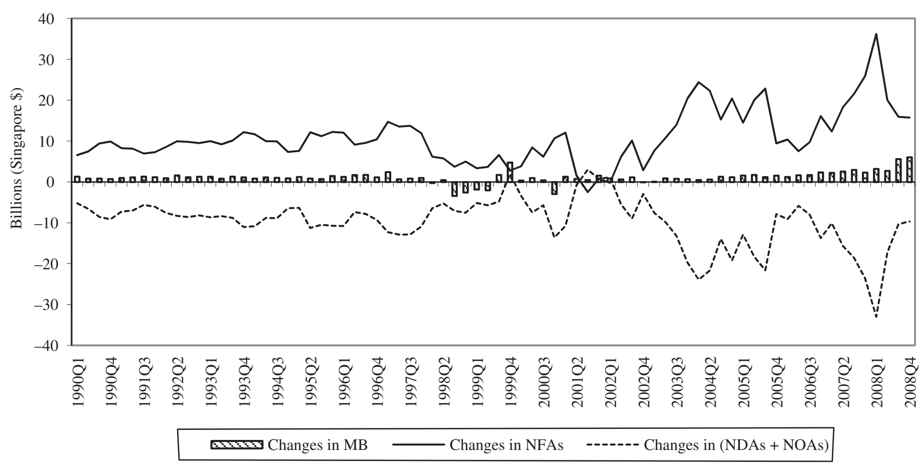

Fig. 5. Quarterly annual change in NFAs, NDAs and reserve money in Singapore, 1990:Q1–2008:Q4
Source: IFS.

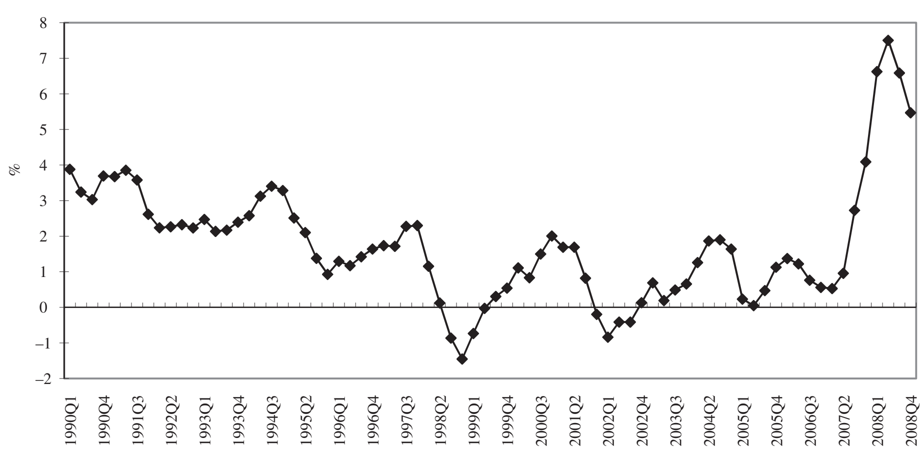

Fig. 6. Inflation (CPI% quarterly annual change) in Singapore, 1990:Q1–2008:Q4
Source: IFS.

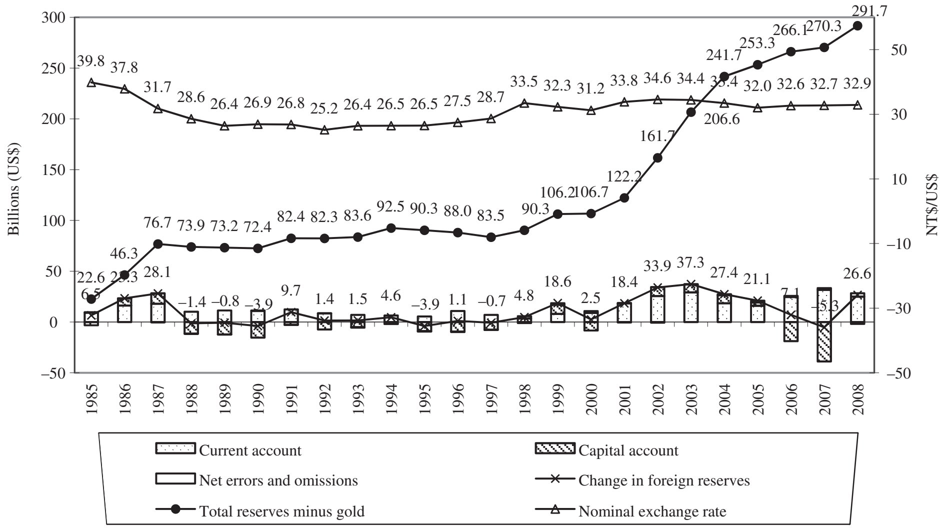

Fig. 7. Trends in Taiwan's balance of payments transactions, 1990–2008
Source: Taiwan Central Bank's official website.

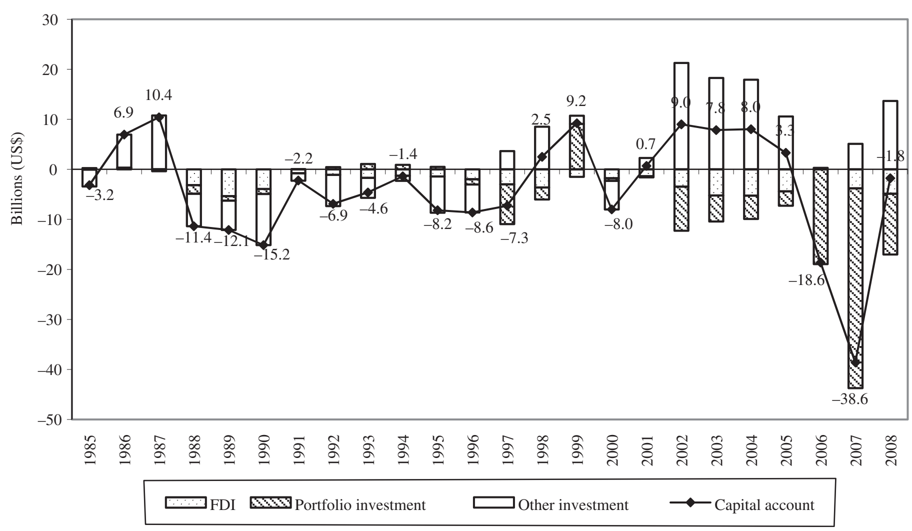

Fig. 8. Capital account components in Taiwan, 1990–2008
Source: Taiwan Central Bank's official website.

in 2006–2008 (Fig. 8). Capital mainly flowed from Taiwan to Mainland China due to an expectation of an appreciation of the Renminbi and the boom in China's asset markets.[3] Interestingly, the errors and omissions balance has been large and positive during this period. By the end of 2008 Taiwan's reserves surpassed US$ 290 billion.

Figure 9 shows CBC's movement in NFAs and NDAs of the monetary base. The dynamic change in NFAs and NDAs reveals strong negative correlations between the two variables. Consequently, the change in the monetary base was quite stable. Figure 10 also shows that inflation has been successfully controlled below 3% since the mid-1990s.

III. Estimating Equations

This article estimates the degree of reserve sterilization in Singapore and Taiwan, as well as the degree

[3] Political disturbance which resulted from the then President Chen Shui-Bian's corruption scandal also decreased investors' (both foreigner and domestic) confidence and their willingness to invest in Taiwan.

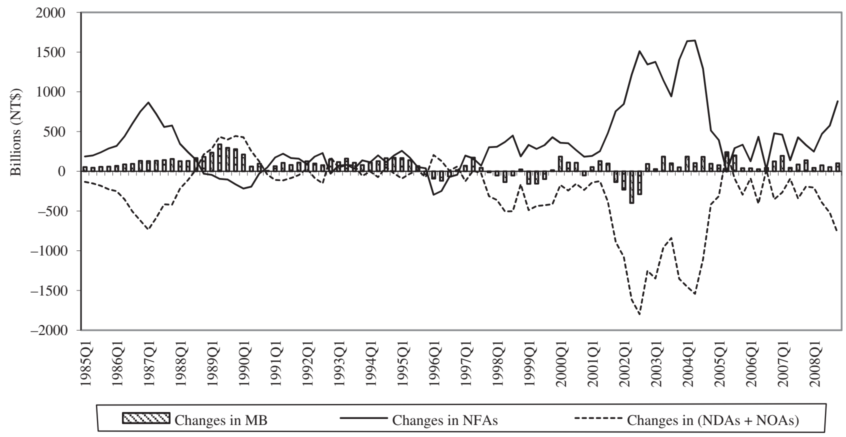

Fig. 9. Quarterly annual change in NFAs, NDAs and reserve money in Taiwan, 1990:Q1–2008:Q4
Source: Taiwan Central Bank's official website.

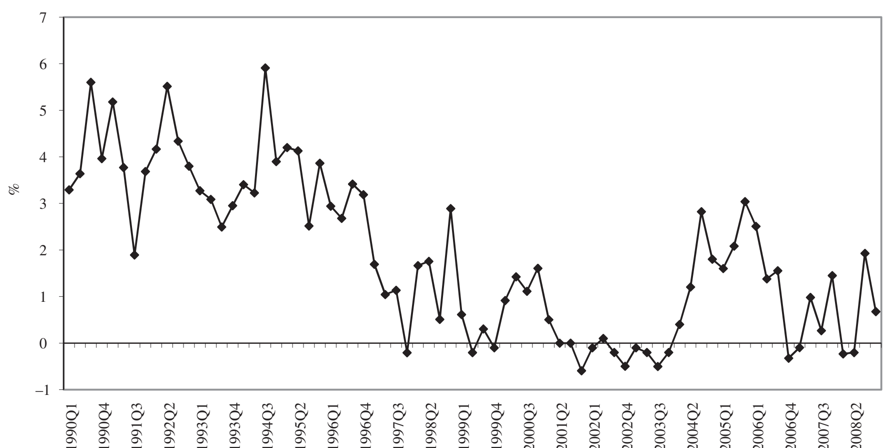

Fig. 10. Inflation (CPI% Quarterly annual change) in Taiwan, 1990:Q1–2008:Q4
Source: Taiwan Central Bank's official website.

of capital mobility as measured by offset coefficients, that is, the fraction of an autonomous change in the domestic monetary base that is offset by international capital flows. To investigate the central bank's ability to control domestic monetary aggregates it is necessary to estimate the extent to which international flows undercut its control. This, in turn, requires the estimation of the counterfactual of the desired rate of monetary growth, that is, estimation of the central bank's monetary reaction function. There is no one correct theoretical specification for central bank's reaction function, but the literature has developed a standard set of variables to be considered within this function. This allows us, at least in principle, to breakdown the inter-relationship between international reserve changes and the monetary base into those relating to autonomous changes in the monetary base (the offset coefficient) and those relating to autonomous changes in international reserve flows (the sterilization coefficient). We also make use of recursive estimation to investigate changes in offset coefficients and sterilization over time.

Model specification

The typical model specification for a set of simultaneous equations is:

$$\Delta NFA_t = \alpha_0 + \alpha_1 \Delta NDA_t + X_1' \alpha_4 + u_{1t} \qquad \text{(1a)}$$

$$\Delta NDA_t = \beta_0 + \beta_1 \Delta NFA_t + X_2' \beta_2 + u_{2t} \qquad \text{(1b)}$$

where X_1 and X_2 are the vector of controls in the balance of payments function and monetary reaction function, respectively. The coefficient α_1 in Equation 1a is the 'offset coefficient', that is, impact of a change in domestic liquidity conditions on capital flows. The expected value of the offset coefficient is bound by zero in the event of no capital mobility and one in the event of perfect capital mobility. The coefficient β_1 in Equation 1b is the 'sterilization coefficient'. The expected value of the sterilization coefficient is -1 if reserve build-up is perfectly sterilized and 0 if the central bank does not sterilize at all. In general, the greater the degree of capital mobility, the less effective is the monetary sterilization.

An obvious concern with estimating Equation 1a and b is the choice of control variables. Most existing empirical studies choose control variables in a rather *ad hoc* manner. A notable exception is BGT (2002) who develops the theoretical basis for the foregoing set of simultaneous equations from explicit minimization of a simple loss function of the monetary authority, subject to a number of constraints that reflect the workings of the economy. We modify the BGT in four important ways as outlined in the Appendix. Based on these modifications, we derive the following set of estimating equations:

$$\begin{aligned}\Delta NFA_t^* = \alpha_0 &+ \sum_{i=0}^{n}\alpha_{1i}\Delta NDA_{t-i}^* + \sum_{i=0}^{n}\alpha_{2i}\Delta mm_{t-i}\\ &+ \sum_{i=1}^{n}\alpha_{3i}(\Delta p_{t-i}) + \sum_{i=1}^{n}\alpha_{4i}Y_{c,t-i}\\ &+ \sum_{i=0}^{n}\alpha_{5i}\Delta G_{t-i} + \sum_{i=1}^{n}\alpha_{6i}\Delta REER_{t-i}\\ &+ \sum_{i=0}^{n}\alpha_{7i}\Delta\left(r_{t-i}^* + E_t s_{t+1-i}\right)\\ &+ \sum_{i=1}^{n}\alpha_{8i}(d_2 - 1)\sigma_{s,t-i} + \varepsilon_t \end{aligned} \tag{2a}$$

$$\begin{aligned}\Delta NDA_t^* = \beta_0 &+ \sum_{i=0}^{n}\beta_{1i}\Delta NFA_{t-i}^* + \sum_{i=0}^{n}\beta_{2i}\Delta mm_{t-i}\\ &+ \sum_{i=1}^{n}\beta_{3i}\Delta p_{t-i} + \sum_{i=1}^{n}\beta_{4i}Y_{c,t-i} + \sum_{i=0}^{n}\beta_{5i}\Delta G_{t-i}\\ &+ \sum_{i=1}^{n}\beta_{6i}\Delta REER_{t-i} + \sum_{i=0}^{n}\beta_{7i}\Delta\left(r_{t-i}^* + E_t s_{t+1-i}\right)\\ &+ \sum_{i=1}^{n}\beta_{8i}(d_1 - 1)\sigma_{r,t-i} + \nu_t \end{aligned} \tag{2b}$$

where

ΔNFA_t^* The quarterly annual change in the adjusted NFAs scaled by the Gross Domestic Product (GDP) (adjustments to be discussed in Section 'Adjusting the NFA and NDA figures').

ΔNDA_t^* The quarterly annual change in the adjusted NDA scaled by the GDP (adjustments to be discussed in Section 'Adjusting the NFA and NDA figures').

Δmm_t The quarterly annual change in money multiplier for M2.[4]

Δp_t The quarterly annual change in consumer price index.

$Y_{c,t}$ Cyclical income.[5]

ΔG_t The quarterly annual change in government expenditure scaled by the GDP.

$\Delta REER_t$ The quarterly annual change in the Real Effective Exchange Rate (REER).

$\Delta(r_t^* + s_{t+1}^e)$ The quarterly annual change in foreign interest rate plus the expected nominal exchange rate (foreign currency per US$).[6]

σ_s The SD of the within quarter change in the bilateral US$ exchange rate.

σ_r The SD of the within quarter change in the monthly domestic interest rate (bank rate).

d_1 A dummy which takes a value of 0 when the domestic money market is in deficit and a value of 2 when it is in surplus.

d_2 A dummy which takes a value of 2 when there is an excess demand for foreign currency (and the central bank is losing reserves) and a value of 0 when foreign currency is in excess supply (and the central bank is stockpiling reserves).

The balance of payments function

'The balance of payments function' (Equation 2a) is essentially a combination of monetary and portfolio balance models and consists of seven control variables. One, a rise in the M2 money multiplier increases domestic money supply and pushes interest

[4] We also tried the M1 money multiplier but the results did not change much.
[5] Cyclical is defined as deviations from trend, where trend is based on the entire sample (i.e. pre- and post-crisis). For a more careful analysis of output gaps in the East Asian economies, see Gerlach and Yiu (2004) who discuss various ways of measuring the output gap in emerging Asian economies that are undergoing significant structural changes. They find that various output gap measures, including estimates derived from the HP-filter rule, are quite highly correlated.
[6] The exchange rate is in logarithm term.

rates down, thus reducing the extent of capital inflows and reserve build-up. More generally, a rising multiplier might also be capturing overall tightening credit policy, including a more restrictive policy towards capital inflows. Two, higher inflation perpetuates concerns about exchange rate depreciation, interest rate hikes and capital losses thereof, hence causing a reduction in reserve build-up.[7] Three, higher lagged real output could worsen the current account (due to the income effect), reducing foreign reserve accumulation. While not explicitly captured in the model, we should note that this variable is a double-edged sword in the sense that a cyclical upturn may act as a pull factor causing more capital to flow into the economy. As such, the prior expected sign of this variable is ambiguous. Four, an expansionary fiscal policy (higher government expenditure) will raise cyclical income and once again worsen the current account as discussed above. Five, foreign reserves will be decumulated due to a decrease in the current account if the lagged REER rises (price effect). The use of one period lags in REER, cyclical output and inflation also reduces the possible endogeneity problems.[8] For instance, it could be argued that greater capital inflows and reserve build-up could lead to a domestic economic boom and an exchange rate appreciation (for instance, see Athukorala and Rajapatirana, 2003). Similarly, we use one period lag of the government expenditure variable to account for the possibility that a contractionary fiscal policy may be a consequence of capital inflows (i.e. fiscal tightening as an instrument of indirect sterilization) rather than the other way around. Six, higher exchange rate adjusted foreign interest rates can also lead to capital withdrawals from the country, hence reducing reserve build-up.[9] Finally, to reduce exchange rate volatility, the central bank tends to buy or sell foreign reserves (i.e. foreign exchange market intervention) when there is an excess supply or demand for foreign currency, respectively.[10] The more volatile the exchange rates the heavier the degree of central bank intervention. Therefore, the expected sign for the interaction term should be negative.

The monetary policy reaction function

The monetary policy reaction function (Equation 2b) also consists of seven control variables in the monetary reaction function in addition to the change of NFAs. These control variables are considered as being important factors influencing monetary policy actions. The monetary authority generally implements a contractionary monetary policy in response to a rise in inflation, an increase in the money multiplier (to curb overall money supply growth) or to an expected exchange rate depreciation (either for its own sake or because of pass-through concerns). Thus, the expected coefficients should be negative. In addition, the monetary authority tends to adopt a tighter monetary policy stance when there is a cyclical rise in income or a more expansionary fiscal deficit, implying negative expected coefficients again.[11] Both a rise in the REER and higher exchange rate adjusted foreign interest rates can lead to a worsening of the balance of payments causing the monetary authority to implement a contractionary monetary policy to attract capital inflows. Finally, to reduce interest rate volatility the central bank will inject or withdraw funds from the market when the domestic money market is in deficit or in surplus, respectively, and the more volatile the domestic interest rate, the greater is the extent of central bank intervention.

IV. Empirics

Data and definitions

The estimation for both Singapore and Taiwan is based on quarterly data over the sample period 1990:Q1 to 2008:Q4. Table 1 summarizes the definitions and sources of the various data used in the estimating equations. The relevant variables such as the change in the 'adjusted' ΔNFA_t^* and ΔNDA_t^*

[7] Additionally, in practice, higher inflation could engender greater uncertainty, leading to reduced capital flows, though using forward looking inflation and cyclical income in the estimations lead to concerns about causality as discussed above.
[8] The limited observations make anything more than a one period lag rather dubious. We, however, did try them and they were not significant.
[9] Two caveats should be noted. One, we use only foreign interest rates rather than interest rate differentials as the domestic interest rates are already captured in the ΔNDA_t term. Two, the other oft-noted push factor, *viz*. industrial country growth, is likely to be highly correlated with domestic country cyclical growth which is already included in the equation. Dasgupta and Ratha (2000) and Montiel and Reinhart (2000) discuss the determinants of capital flows into developing economies.
[10] There is a body of literature – primarily pertaining to developed countries – looking at the effectiveness of foreign exchange intervention. For instance, see Sarno and Taylor (2001) and Taylor (2004).
[11] Of course there are exceptions. For instance, during an economic downturn there could be simultaneous use of expansionary monetary and fiscal policies, and *vice versa* during an upturn in economic activity.

Table 1. Definitions and measurement of the variables used in empirical study

Variables	Definitions	Measured as	Data (source)
NFA_t^*	Foreign reserves denominated in domestic currency minus foreign liabilities	Reserve (\$) $\times s_t -$ Foreign liabilities (domestic currency)	IFS and Taiwan Central Bank's official website
ΔNFA_t^*	The quarterly annual change in NFA_t^* excluding revaluation effect	$\left[NFA_t^* - NFA_{t-4}^*\left(\frac{s_t}{s_{t-4}}\right)\right] \Big/ GDP_t$	IFS and Taiwan Central Bank's official website
ΔNDA_t^*	The quarterly annual change in (net domestic assets + net other assets) + revaluation effect scaled by the GDP.	$\left[\Delta NDA_t + \Delta NOA_t + NFA_{t-1}^*\left(\frac{s_t}{s_{t-4}} - 1\right)\right] \Big/ GDP_t$	IFS and Taiwan Central Bank's official website
s_t	Spot exchange rate (average)	Domestic currency/US\$	IFS and Taiwan Central Bank's official website
mm_t	Money multiplier for M2	M2/monetary base	IFS and Taiwan Central Bank's official website
Δmm_t	The change in money multiplier for M2	$\log(mm_t) - \log(mm_{t-4})$	
$\Delta REER_t$	The quarterly annual change in REER.	$\log(REER_t) - \log(REER_{t-4})$	IFS(Singapore) and BIS(Taiwan)
$y_{c,t}$	Cyclical income. The real output deviated from its trend scaled by the trend. The trend is measured by HP-filter.	$[\log(RealGDP) -$ HP $-$ filter trend]/HP filter trend	IFS and AREMOS dataset
Δp_t	Inflation rate	$\log(cpi_t) - \log(cpi_{t-4})$	IFS and Taiwan Central Bank's official website
$\Delta(r_t^* + E_t s_{t+1})$	The quarterly annual change in exchanged adjusted foreign interest rate. The foreign interest rate is the interest rate for US 3-month treasury bill.	$\Delta[r_t^* + \ln(s_{t+1})]$	IFS and Taiwan Central Bank's official website
ΔG_t	The quarterly annual change in government fiscal deficit scaled GDP	$\Delta G_t / GDP_t$	IFS and AREMOS dataset

Table 2. ADF unit roots test for Singapore and Taiwan data

	ADF test statistic H_0: variable has a unit root			
Variables	Type of test	Singapore	Type of test	Taiwan
ΔNDA_t^*	None	−1.760*	None	−2.243**
ΔNFA_t^*	None	−1.623*	Intercept	−2.654*
Δmm_t	None	−2.264**	Intercept with trend	−4.671***
$\Delta REER_t$	None	−2.283**	Intercept	−4.134***
$y_{c,t}$	None	−4.212***	None	−4.213***
Δp_t	Intercept	−3.440**	Intercept	−1.784*
$\Delta(r_t^* + E_t s_{t+1})$ (Perfect foresight)	None	−2.342**	None	−3.035***
ΔG_t	None	−5.994***	Intercept with trend	−10.843***
$\sigma_{s,t}$	None	−4.599***	Intercept with trend	−5.523***
$\sigma_{r,t}$	None	−4.866***	None	−5.622***

Note: *, ** and *** denote significance at more than 10, 5 and 1%, respectively.

(where * denotes adjustments which are discussed in Section 'Adjusting the NFA and NDA figures') and ΔG_{t-1} are scaled by GDP. To check for stationarity we applied the standard unit root test using the Augmented Dickey Fuller (ADF) to each of the variables and found them all to be stationary at the 10% level of significance with the exception of the risk adjusted foreign interest rate (Table 2).[12] We used the Hodrick–Prescott (HP) method to measure the trend of real output. In addition, we used the SD of the within quarter change in the daily US$ bilateral exchange rate and short-term bank rates to proxy the volatility of exchange rate and volatility of domestic interest rate, respectively. Specifically, for Taiwan we use the money market rate and for Singapore we use the 3-month interbank rate. Since we do not have consistent quarterly data on forward rates we assume that economic agents have perfect foresight to proxy the expected exchange rates for the next period.

Adjusting the NFA and NDA figures

As both the NDA_t and NFA_t are based on the monetary authorities' balance sheet, care must be taken in accounting for nonpolicy-related changes in the variables such as the revaluation effects due to gold value and exchange rate fluctuations.[13] To exclude monetary gold from the foreign assets, we use the product of foreign reserves denominated in US dollar and the bilateral exchange rate (domestic currency/US$) to proxy foreign assets. The NFAs without revaluation effect can be stated as follows:

$$NFA_t = (R_t \times s_t) - FL_t \tag{3}$$

where R_t is the foreign exchange reserves denominated in US dollars, s_t is the exchange rate against US dollars and FL_t refers to the central bank foreign liabilities.

We use the $(R_t \times s_t)$ rather than FA_t as there are some differences between the two in the case of many of the emerging Asian economies, and from an analytical perspective, monetary sterilization pertains specifically to international reserves.[14] However, the problem with using $(R_t \times s_t)$ is that reserve values could change because of currency fluctuations, but these valuation effects will be captured in the bank capital and will not alter the domestic currency value of the banking system's holding of high-powered money.[15] As such we need to exclude these effects before estimation. Ideally, if we had the currency

[12] Siklos (2000) pointed out a similar problem with the Hungarian–German interest rate differential and has argued that interest rates should not be difference stationary. The ADF results were confirmed by the Kwiatkowski–Phillips–Schmidt–Shin (KPSS) test.

[13] Another factor includes interest earnings earned from foreign reserves accumulation. Given the low interest rates in both economies, we ignore this factor.

[14] Loosely speaking, this should correspond to the liquid part of foreign assets of the central bank. Ideally, we should also be using only the liquid portion of central bank foreign liabilities. These data are not available.

[15] In general, the monetary authority recognizes the end-year revaluation of foreign currency liabilities and assets in the profit and loss account of the income statement. Since the end-year income statement balance will be included in the equity (K) account of balance sheet, the change of NFAs due to the revaluation effect can be offset by the change of equity so that the domestic monetary base will be unchanged. In other words, if NFA rises because of an increase in e_t, $M\bar{B} = NFA \uparrow + NDA + NOA - K \uparrow$. However, in both Singapore's and Taiwan's cases, they include equity account with NOA. Therefore, on their balance sheet, MB = NFA + NDA + NOA. The revaluation effect is recognized in the Net Other Assets (NOA) account.

composition of reserves we could adjust for the valuation changes. Given that such data are not available, the best we can do is assume that all the reserves are held in US dollar and adjust the reserves for changes in the bilateral US dollar rate.[16] Since the revaluation effect is the change in the NFAs due to exchange rate fluctuation, it can be measured as follows:

$$\text{Revaluation effect} = NFA_{t-1}\left(\frac{s_t}{s_{t-1}} - 1\right) \quad (4)$$

Therefore, the change in the adjusted NFA $= \Delta NFA_t^* = NFA_t - NFA_{t-1}(s_t/s_{t-1})$. The adjusted variable excludes the price or valuation effect, which as noted, should have no direct impact on liquidity. The change in adjusted NDA $= \Delta NDA_t^*$ is derived as $\Delta NDA_t + \Delta NOA_t - \Delta K_t +$ revaluation effect or $\Delta NDA_t + \Delta NOA_t - \Delta K_t + NFA_{t-1}((s_t/s_{t-1}) - 1)$.

V. Empirical Results

We first use the Two-Stage Least Square (2SLS) method to estimate the simultaneous Equation 2a and 2b. We apply autocorrelation and heteroscedasticity tests to the residuals from the estimated equations and use Newey–West Heteroscedasticity and Autocorrelation Consistent (HAC) covariance estimates if there is a problem.[17] The Breusch–Godfrey serial correlation Lagrange Multiplier (LM) test is passed after including Autoregression (AR) terms in the regressions. Autoregressive Conditional Heteroscedasticity (ARCH) LM test is also used to test ARCH in the residuals with lags equal to 1. Since the correlation between the two equations is about 0.9 for both Singapore and Taiwan cases, we also applied the 3SLS to correct for the correlation problem.

Point estimates

Table 3 reports the empirical results of 2SLS and 3SLS for Singapore. The estimated offset and sterilization coefficients are between 0.9 and 1, indicating that Singapore had a high degree of capital mobility and the MAS undertook significant sterilization operations. The money multiplier has the correct sign in both the balance of payments function and monetary reaction functions and is statistically and economically significant. The exchange rate adjusted foreign interest rate variable is negative and significant, as would be expected *a priori*. The large coefficient values suggest that Singapore is highly sensitive to interest sensitive capital flows, as would be expected *a priori* for an international financial centre. The government expenditure is negative and statistically significant in the case of the balance of payments function using 2SLS. The other variables are statistically insignificant in all the other functions using both 2SLS and 3SLS.

Taiwan's empirical results are shown in Table 4. The estimated offset coefficients are between 0.9 and 1, while the estimated sterilization coefficient is just above 1. This suggests that Taiwan had a fairly high degree of *de facto* capital mobility and the CBC also undertook aggressive sterilization operations. The estimated coefficients for the change of the money multiplier are negative and statistically significant for both the functions. The lagged inflation is statistically significant in both functions but is the incorrect sign. All other variables are statistically insignificant in both cases.

Recursive estimates

We also make use of recursive estimation to investigate changes in offset coefficients and sterilization over time.[18] Figure 11(a) and (b) shows Singapore's recursive estimated offset and sterilization coefficients, respectively. The movement of estimated offset coefficients reveals Singapore's degree of *de facto* capital mobility to have increased significantly after the Asian crisis period. Specifically, the estimated offset coefficient rose from 0.6 in 1998:Q1 during the height of the regional crisis and recession to an average of 0.7. Since then, the degree of capital mobility has gradually increased to around 0.9, near perfect capital mobility. The recursive estimated sterilization coefficients indicate that the MAS has

[16] Of course, we could assume different scenarios such as Prasad and Wei (2005) did in the case of China. However, we have no basis of making such assumptions and given the number of other issues we deal with in this article, it seems wise to refrain from making such *ad hoc* adjustments.

[17] Newey and West (1987) derived a consistent covariance matrix estimator in the presence of both heteroscedasticity and autocorrelation. Since we use the Newey–West HAC estimates we do not need to include lagged-dependent terms as done by BGT (2002) and others. Serial correlation LM test is used to check for the autocorrelation while White's heteroscedasticity test is used to test the heteroscedasticity in the residuals.

[18] The coefficients are initially estimated for the period 1990:Q1 to 1998:Q1. Then each time we add one observation and re-estimate the offset and sterilization coefficients by using 3SLS.

Table 3. Singapore – estimated simultaneous equations, 1990:Q1–2008:Q4

	2SLS		3SLS	
	ΔNFA_t^*	ΔNDA_t^*	ΔNFA_t^*	ΔNDA_t^*
Constant	0.060*** (0.014)	0.048*** (0.013)	0.049*** (0.011)	0.053*** (0.013)
ΔNDA_t^* (offset)	−0.868*** (0.045)	–	−0.922*** (0.031)	–
ΔNFA_t^* (sterilization)	–	−1.049*** (0.052)	–	−1.090*** (0.035)
Δmm_t	−0.185** (0.074)	−0.152** (0.066)	−0.150** (0.061)	−0.148** (0.064)
Δp_{t-1}	0.208 (0.882)	−0.323 (0.855)	−0.053 (0.588)	−0.027 (0.623)
$Y_{c,t-1}$	−0.039 (0.133)	−0.057 (0.138)	−0.031 (0.109)	−0.030 (0.115)
ΔG_t	−0.198** (0.082)	−0.092 (0.094)	−0.123 (0.090)	−0.127 (0.098)
$\Delta(r_t^* + E_t s_{t+1})$	−0.808*** (0.155)	−0.716*** (0.187)	−0.661*** (0.121)	−0.732*** (0.148)
$\Delta REER_{t-1}$	0.247 (0.278)	0.341 (0.311)	0.278 (0.236)	0.304 (0.251)
$(d_2-1)\sigma_{s,t-1}$	0.256 (0.512)	–	0.212 (0.232)	–
$(d_1-1)\sigma_{r,t-1}$	–	−0.037* (0.020)	–	−0.006 (0.007)
$AR(1)$	−0.242** (0.102)	−0.232* (0.120)	−0.262*** (0.095)	−0.252*** (0.092)
$AR(4)$	−0.485*** (0.146)	−0.513*** (0.147)	−0.516*** (0.095)	−0.523*** (0.093)
Adj. R^2	0.957	0.948	0.956	0.943
SE of the regression	0.057	0.061	0.058	0.063
Breusch–Godfrey serial correlation LM test (p-value)	3.724 (0.447)	5.724 (0.221)	–	–
ARCH LM test (p-value)	0.116 (0.733)	0.150 (0.698)	–	–

Notes: Here serial correlation LM test is used to test fourth-order autocorrelation, while ARCH LM test is used to test ARCH in the residuals with lags equal to one.
*, ** and *** denote significance at more than 10, 5 and 1%, respectively.

Table 4. Taiwan – estimated simultaneous equations, 1990:Q1–2008:Q4

	2SLS		3SLS	
	ΔNFA_t^*	ΔNDA_t^*	ΔNFA_t^*	ΔNDA_t^*
Constant	0.073*** (0.011)	0.066*** (0.015)	0.066*** (0.013)	0.071*** (0.015)
ΔNDA_t^* (offset)	−0.861*** (0.029)	–	−0.915*** (0.028)	–
ΔNFA_t^* (sterilization)	–	−1.052*** (0.041)	–	−1.088*** (0.034)
Δmm_t	−0.918*** (0.073)	−1.060*** (0.089)	−0.975*** (0.063)	−1.065*** (0.062)
Δp_{t-1}	0.998** (0.411)	1.346*** (0.493)	1.247*** (0.401)	1.373*** (0.432)
$Y_{c,t-1}$	0.234 (0.197)	0.210 (0.233)	0.222 (0.228)	0.240 (0.249)
ΔG_t	−0.046 (0.094)	−0.057 (0.095)	−0.050 (0.117)	−0.054 (0.128)
$\Delta(r_t^* + E_t s_{t+1})$	−0.008 (0.112)	0.012 (0.124)	−0.007 (0.076)	−0.006 (0.083)
$\Delta REER_{t-1}$	0.018 (0.103)	−0.020 (0.132)	−0.008 (0.126)	−0.011 (0.137)
$(d_2-1)\sigma_{s,t-1}$	−0.005 (0.014)	–	−0.0001 (0.005)	–
$(d_1-1)\sigma_{r,t-1}$	–	0.003 (0.007)	–	0.0003 (0.004)
$AR(1)$	0.399*** (0.091)	0.388*** (0.110)	0.394*** (0.092)	0.394*** (0.092)
$AR(2)$	0.487*** (0.101)	0.474*** (0.108)	0.480*** (0.092)	0.480*** (0.092)
$AR(3)$	0.382*** (0.097)	0.388*** (0.101)	0.373*** (0.092)	0.372*** (0.092)
$AR(4)$	−0.668*** (0.092)	−0.631*** (0.100)	−0.658*** (0.092)	−0.657*** (0.092)
Adj. R^2	0.968	0.966	0.968	0.965
SE of the regression	0.035	0.038	0.036	0.039
Breusch–Godfrey serial correlation LM test (p-value)	3.521 (0.475)	2.903 (0.574)	–	–
ARCH LM test (p-value)	1.211 (0.271)	0.306 (0.580)	–	–

Notes: Here serial correlation LM test is used to test fourth-order autocorrelation, while ARCH LM test is used to test ARCH in the residuals with lags equal to one.
*, ** and *** denote significance at more than 10, 5 and 1%, respectively.

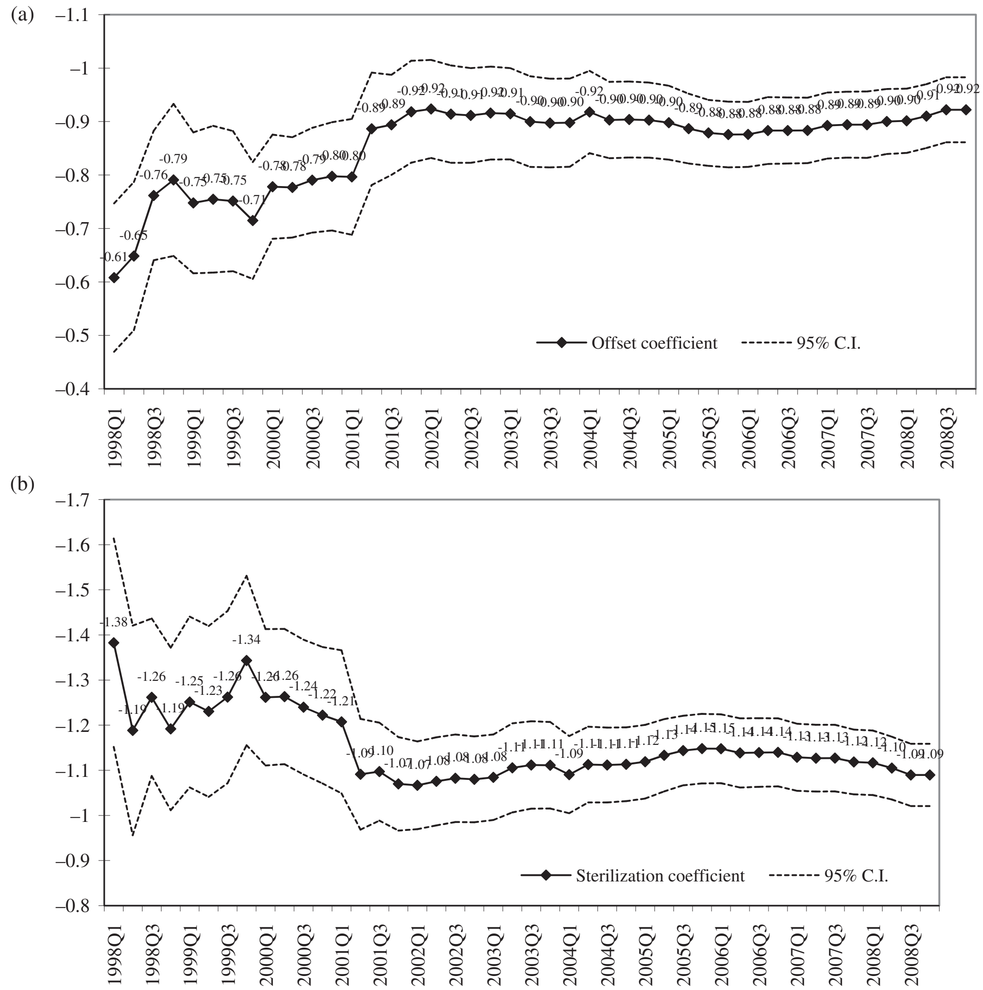

Fig. 11. Singapore: recursive estimated (a) offset coefficients and (b) 1998:Q1–2008:Q4 sterilization coefficients

heavily sterilized most of the reserve accumulation. The findings regarding almost complete sterilization by MAS is consistent with the following comment by the authorities:

> Over the years, MAS' FX intervention operations have been typically of the 'lean against the wind' type, particularly in moderating the appreciation of the S$. By virtue of its money market operating procedures to provide sufficient liquidity to meet banks' demand for reserve balances, sterilisation of MAS' FX intervention operations occurs automatically . . . To the extent that the liquidity in the banking system is restored to a level sufficient to meet banks' demand for reserve balances . . . MAS' FX intervention operations can be said to have been sterilised in a broader sense (MAS, 2003, p. 24).

Figure 12(a) and (b) shows Taiwan's recursive estimated offset and sterilization coefficients, respectively. The recursive estimated offset coefficients were high and stable at around 1 between 1998:Q1 and 2001:Q3, indicating a fairly high degree of capital mobility in Taiwan. There has, however, been a slight drop in the offset coefficient since then, hovering at 0.9. There was an upward spike in the intensity of sterilization since early 2002 with the coefficient averaging slightly over 1, implying complete sterilization.

Robustness checks

We undertook a number of robustness checks, but for the sake of parsimony the estimated equations are not included in this article.[19] Among the more significant checks are the following. First, we replaced the lagged

[19] They are available from the authors on request.

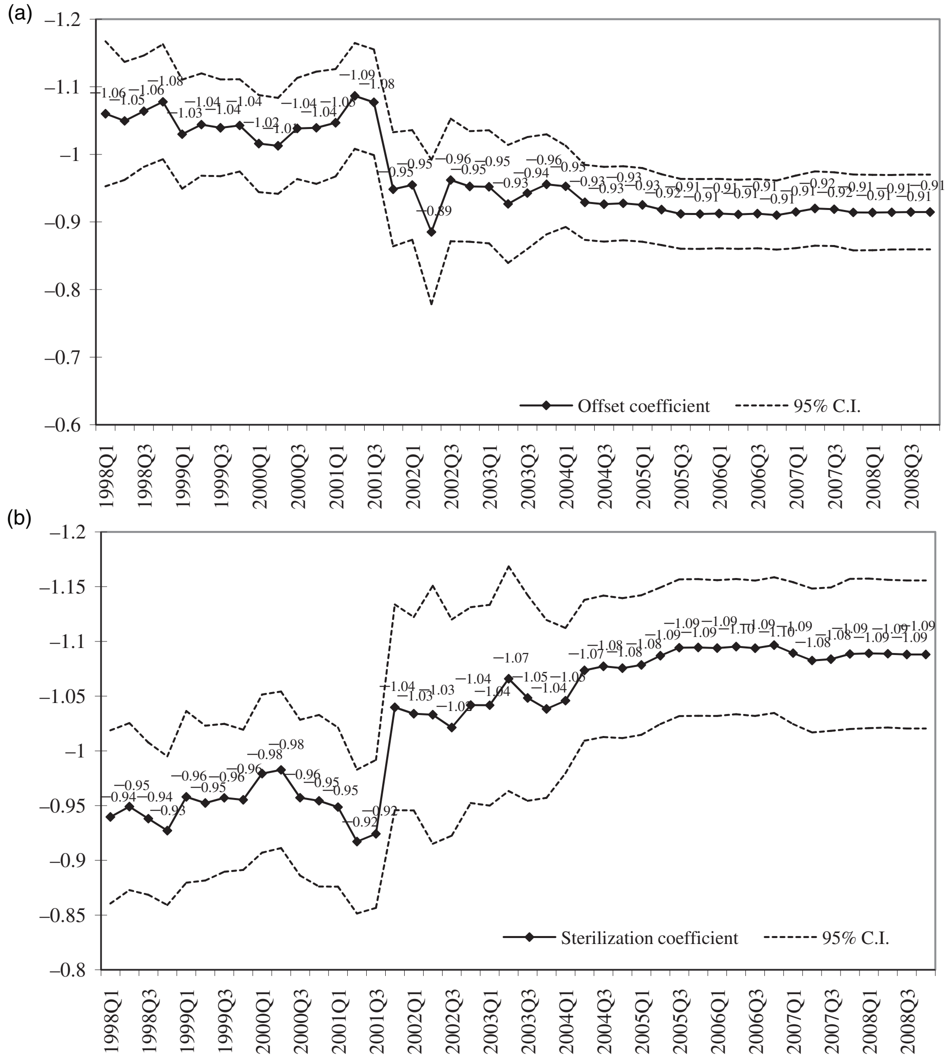

Fig. 12. Taiwan: recursive estimated (a) offset coefficients and (b) sterilization coefficients

cyclical income and lagged REER with the trade balance (as done by BGT (2002) and others). Second, we included quarterly dummies to account for possible seasonality. Third, we replaced the change in REER with deviation of REER from trend (as ideally one needs to use a measure of real exchange rate misalignment rather than change). Fourth, since theory has not offered guidance on lag structures, we tried up to two lags of all independent variables including adding the lagged-dependent variables. In all of the cases, the results were largely unchanged.

VI. Concluding Remarks

Most monetary models of the exchange rate and balance of payments assume no sterilization so that large reserve accumulations would automatically lead to rapid growth in domestic money and credit. We find that the central banks in both economies have been actively mopping up the liquidity consequences of the foreign exchange intervention over the period 1990 to 2008. However, sufficiently high levels of international capital mobility would make effective sterilization impossible, no matter the intensity of efforts of the domestic monetary authorities. Our empirical results suggest that since 2001 both Singapore and Taiwan have a high degree of – but not perfect – capital mobility. This lack of complete sterilization has likely allowed for sterilization to be somewhat effective in both economies, though it has perpetuated further inflows, and therefore has had to be maintained on a sustained basis.

Acknowledgements

This article has drawn on joint work and discussions on the subject with Tom Willett. Also, valuable research assistance by Nicola Virgill is gratefully acknowledged, and so are the very useful comments from an anonymous referee. Financial support from Central University of Finance and Economics 121 Youth Scholar Fund is acknowledged. The usual disclaimer applies.

References

Athukorala, P. C. and Rajapatirana, S. (2003) Capital inflows and the real exchange rate: a comparative study of Asia and Latin America, *The World Economy*, **26**, 613–37.

Brissimis, S., Gibson, H. and Tsakalotos, E. (2002) A unifying framework for analyzing offsetting capital flows and sterilisation: Germany and the ERM, *International Journal of Finance and Economics*, **7**, 63–78.

Cavoli, T. and Rajan, R. S. (2009) *Exchange Rate Regimes and Macroeconomic Management in Asia?*, Hong Kong University Press, Hong Kong.

Dasgupta, D. and Ratha, D. (2000) What factors appear to drive private capital flows to developing countries? And how does official lending respond?, Policy Research Working Paper No. 2392, The World Bank, Washington, DC.

Gerlach, S. and Yiu, M. (2004) Estimating output gaps in Asia: a cross-country study, *Journal of Japanese and International Economics*, **18**, 115–36.

Khor, H. E., Robinson, E. and Lee, J. (2004) Managed floating and intermediate exchange rate systems: the Singapore experience, Staff Paper No. 37, Monetary Authority of Singapore (MAS), Singapore.

Monetary Authority of Singapore (MAS) (2003) *Monetary Policy Operations in Singapore*, MAS, Singapore.

Montiel, P. and Reinhart, C. (2000) The dynamics of capital movements to emerging economies during the 1990s, in *Short-term Capital Movements and Balance of Payments Crises* (Eds) S. Griffith-Jones and M. Montes, Oxford University Press, Oxford, pp. 3–29.

Newey, W. K. and West, K. D. (1987) Hypothesis testing with efficient method of moments estimation, *International Economic Review*, **28**, 777–87.

Ouyang, A., Rajan, R. S. and Willett, T. D. (2008) Managing the monetary consequences of reserve accumulation in emerging Asia, *Global Economic Review*, **36**, 87–99.

Pontines, V. and Rajan, R. S. (2008) 'Fear of appreciation' not 'fear of floating'? Foreign exchange market intervention in emerging Asia, *mimeo*, November.

Prasad, E. and Wei, S. J. (2005) Understanding the structure of cross-border capital flows: the case of China, *mimeo*, International Monetary Fund (IMF).

Rajan, R. S., Sen, R. and Siregar, R. (2002) Hong Kong, Singapore and the East Asian crisis: how important were trade spillovers?, *The World Economy*, **25**, 503–37.

Sarno, L. and Taylor, M. P. (2001) Official intervention in the foreign exchange market: is it effective and, if so, how does it work?, *Journal of Economic Literature*, **39**, 839–68.

Siklos, P. (2000) Capital flows in a transitional economy and the sterilisation dilemma: the Hungarian experience, 1992–97, *Journal of Policy Reform*, **3**, 413–38.

Taylor, M. P. (2004) Is official exchange rate intervention effective?, *Economica*, **71**, 1–12.

Appendix: Theoretical Basis for the Simultaneous Equations

An obvious concern with estimating monetary policy and balance of payment reaction functions is the choice of control variables. Most existing empirical studies have chosen control variables based on informal theorizing. One exception is the paper by BGT (2002), which develops a formal theoretical model from which the foregoing set of simultaneous equations are derived from explicit minimization of a simple loss function of the monetary authority, subject to a number of constraints that reflect the workings of the economy.

Following Ouyang *et al.* (2008), we modify the BGT in four important ways: (1) Unlike the original BGT model which assumes that the central bank is concerned about the deviation of the exchange rate from a target *level* and therefore incorporates the exchange rate in the loss function directly, instead we assume that the central bank is primarily concerned with exchange rate *volatility*. Undoubtedly, most central banks are concerned with both, but it is much less difficult to operationalize exchange-rate volatility than the target exchange rate; (2) Unlike the original BGT model we assume that the exchange rate impacts inflation directly via pass through. In other words, the monetary authority is not concerned about the exchange rate for its own sake, but rather because of its impact on inflation and trade; (3) We endogenize the current account by assuming it is affected by both income and price (exchange rate) effects; (4) We also incorporate the role of government spending on cyclical output. These modifications are broadly consistent with the managing floating regimes operated by many emerging Asian economies.

In our modified version of the BGT model, the loss function of the monetary authority is:

$$L_t = \beta(\Delta p_t)^2 + \gamma(Y_{c,t})^2 + \delta(\sigma_{r,t})^2 + \varepsilon(\sigma_{s,t})^2 \quad \text{(A1)}$$

The monetary authority's loss function is determined by the change in the logarithm of the price level (i.e. the difference in p_t and p_{t-1}); cyclical income ($Y_{c,t}$); and the volatilities of the interest rate ($\sigma_{r,t}$) and the exchange rate ($\sigma_{s,t}$). All the parameters are assumed to be positive.

The evolution of key variables including inflation and cyclical income is discussed below:

Inflation

The evolution of inflation can be written as follows:

$$\Delta p_t = \pi_1[(\Delta NFA_t + \Delta NDA_t)mm_t + MB_t\Delta mm_t] + \pi_2\Delta p_{t-1} + \pi_3\Delta s_t \quad \text{(A2)}$$

where for $\pi_1 > 0, 0 < \pi_2 < 1, \pi_3 > 0$, MB_t is the monetary base and mm_t is the money multiplier. Equation A2 states that inflation is a monetary phenomenon with a lagged effect. In addition, depreciation of the nominal exchange rate (rise in s_t) could increase inflationary pressures due to increased prices of tradable goods.

Cyclical income

The evolution of cyclical income can be written as follows:

$$Y_{c,t} = \varphi_1[(\Delta NFA_t + \Delta NDA_t)mm_t + MB_t\Delta mm_t] + \varphi_2 Y_{c,t-1} + \varphi_3\Delta G_t$$
$$\varphi_1 > 0, 0 < \varphi_2 < 1, \varphi_3 > 0 \quad \text{(A3)}$$

where G_t is the government expenditure. We assume that both expansionary fiscal and monetary policies can boost cyclical output.

Balance of payments

The balance of payments is defined as usual (ignoring errors and omissions):

$$\Delta NFA_t = CA_t + \Delta NK_t \quad \text{(A4)}$$

where CA is the current account balance and ΔNK_t is the net capital inflow in time t. The current account in turn is assumed to depend simply on both cyclical output and the lagged REER (to capture inertial effects) in a linear manner:

$$CA_t = \alpha_0 + \alpha_1 Y_{c,t} + \alpha_2\Delta REER_{t-1}, \quad \alpha_1 < 0, \ \alpha_2 < 0 \quad \text{(A5)}$$

where REER is the real effective exchange rate (rise implies a currency appreciation).

The net capital inflow is assumed to depend imperfectly on the uncovered interest differentials:

$$\Delta NK_t = (1/c)\Delta\left(s_t - E_t s_{t+1} + r_t - r_t^*\right) \quad \text{(A6)}$$

where s_t is the current exchange rate (logarithm); $E_t s_{t+1}$ is the current expectation of the exchange rate at time $t+1$; r_t is the domestic interest rate; r_t^* is the foreign interest rate and c represents the degree of substitutability between domestic and foreign assets, that is, the degree of international capital mobility. This in turn is affected by the extent of capital controls.

The interest rate is determined by the change in money supply:

$$\Delta r_t = -\psi_1[(\Delta NDA_t + \Delta NFA_t)mm_t + MB_t\Delta mm_t] \quad \psi_1 > 0 \quad \text{(A7)}$$

With appropriate substitutions into Equation A2 we derive:

$$\begin{aligned}\Delta p_t = {} & (\pi_1 mm_t + c\pi_3 + \pi_3 c\alpha_1\varphi_1 mm_t + \pi_3\psi_1 mm_t)\Delta NFA_t \\ & + (\pi_1 mm_t + \pi_3 c\alpha_1\varphi_1 mm_t + \pi_3\psi_1 mm_t)\Delta NDA_t \\ & + (\pi_1 MB_t + \pi_3 c\alpha_1\varphi_1 MB_t + \pi_3\psi_1 MB_t)\Delta mm_t \\ & + (\pi_3 c\alpha_1\varphi_2)Y_{c,t-1} + (\pi_2)\Delta p_{t-1} + (\pi_3 c\alpha_1\varphi_3)\Delta G_t \\ & + (\pi_3 c\alpha_2)\Delta REER_{t-1} + (\pi_3)\Delta(r_t^* + E_t s_{t+1})\end{aligned} \quad \text{(A8)}$$

Interest rate volatility

Interest rate volatility follows the original BGT model:

$$\sigma_{r,t} = \eta\sigma_{r,t-1} - \theta|\Delta NDA_t| \quad \eta, \theta > 0 \quad \text{(A9)}$$

Interest rate volatility is assumed to depend negatively on the absolute amount of intervention undertaken by the central bank in the domestic money market. For estimation purposes Equation A9 is transformed into nonabsolute terms. For example, the original BGT model assumes that the central bank injects liquidity ($\Delta NDA_t > 0$) to prevent an interest rate rise while the money market is in deficit. The same logic can be applied to the case when the money market is in surplus. When money market is in surplus, the central bank withdraws money to prevent interest rates from falling so that $\Delta NDA_t < 0$.

Therefore, if the money market is in deficit, $\Delta NDA_t > 0$, Equation A9 can be rewritten as follows:

$$\sigma_{r,t} = \eta\sigma_{r,t-1} - \theta(\Delta NDA_t - d_1\Delta NDA_t) \quad \text{(A9a)}$$

where d_1 is the dummy which takes on a value of 0 when the money market is in deficit and a value of 2 when it is in surplus.

Exchange rate volatility

Exchange rate volatility follows the original BGT model:

$$\sigma_{s,t} = \eta\sigma_{s,t-1} - \theta|\Delta NFA_t| \quad \eta, \theta > 0 \quad \text{(A10)}$$

Exchange rate volatility depends negatively on the absolute amount of intervention undertaken by the central bank in the foreign exchange market.[20] Using the same logic as in the case of interest rate volatility, we can redefine Equation A10 as follows:

$$\sigma_{s,t} = \kappa\sigma_{s,t-1} - \varsigma(\Delta NFA_t - d_2\Delta NFA_t) \quad \kappa, \varsigma > 0 \quad \text{(A10a)}$$

where d_2 is a dummy variable which takes on a value of 2 when there is an excess demand for foreign currency (and the central bank is losing reserves) and a value of 0 when foreign currency is in excess supply (and the central bank is stock-piling reserves).

As is typical of a managed floater, we assume that the central bank consciously attempts to alter domestic credit (and thus interest rates) and undertakes foreign exchange rate intervention (i.e. managed float) with the aim of minimizing its loss function (Equation A1). It is important to keep in mind that since we are not attempting to specify a policy rule for the monetary authority, it is reasonable to derive an equation for ΔNDA_t as opposed to interest rates despite most of the regional central banks having adopted the interest rate as the policy instrument. Estimating a set of simultaneous equations with ΔNDA_t and as dependent variables is more consistent with the literature.

Given this we can solve for $\partial L_t/\partial\Delta NDA_t \neq 0$ $\partial L_t/\partial\Delta NFA_t = 0$, and after substituting the constraints into the loss function, we derive two reduced-form equations:

$$\begin{aligned}
\Delta NFA_t = &-\{[\beta c\pi_3(\pi_1 + \pi_3\psi_1 + c\alpha_1\varphi_1\pi_3)mm_t + \beta(\pi_1 + \pi_3\psi_1 + c\alpha_1\varphi_1\pi_3)^2 mm_t^2 + r\varphi_1^2 mm_t^2]/u_1\}\Delta NDA_t \\
&- \{[\beta c\pi_3(\pi_1 + \pi_3\psi_1 + c\alpha_1\varphi_1\pi_3)MB_t + \beta(\pi_1 + \pi_3\psi_1 + c\alpha_1\varphi_1\pi_3)^2 mm_t MB_t + r\varphi_1^2 mm_t MB_t]/u_1\}\Delta mm_t \\
&- \{[\beta\pi_2(\pi_3 c + (\pi_1 + \pi_3\psi_1 + c\alpha_1\varphi_1\pi_3)mm_t)]/u_1\}\Delta p_{t-1} \\
&- \{[\beta c\alpha_1\varphi_2\pi_3(\pi_3 c + (\pi_1 + \pi_3\psi_1 + c\alpha_1\varphi_1\pi_3)mm_t) + r\varphi_1\varphi_2 mm_t]/u_1\}Y_{c,t-1} \\
&- \{[\beta c\alpha_1\varphi_3\pi_3(\pi_3 c + (\pi_1 + \pi_3\psi_1 + c\alpha_1\varphi_1\pi_3)mm_t) + r\varphi_1\varphi_3 mm_t]/u_1\}\Delta G_t \\
&- \{[\beta c\alpha_2\pi_3(\pi_3 c + (\pi_1 + \pi_3\psi_1 + c\alpha_1\varphi_1\pi_3)mm_t)]/u_1\}\Delta REER_{t-1} \\
&- \{[\beta\pi_3(\pi_3 c + (\pi_1 + \pi_3\psi_1 + c\alpha_1\varphi_1\pi_3)mm_t)]/u_1\}\Delta(r_t^* + E_t s_{t+1}) \\
&- \{[\varepsilon\varsigma\kappa(d_2 - 1)]/u_1\}\sigma_{s,t-1} \qquad \text{(A11a)}
\end{aligned}$$

where $u_1 = \beta[\pi_3 c + (\pi_1 + \pi_3\psi_1 + c\alpha_1\varphi_1\pi_3)mm_t]^2 + r\varphi_1^2 mm_t^2 + \varepsilon\varsigma^2(d_2 - 1)^2 > 0$.

$$\begin{aligned}
\Delta NDA_t = &-\{[\beta c\pi_3(\pi_1 + \pi_3\psi_1 + c\alpha_1\varphi_1\pi_3)mm_t + \beta(\pi_1 + \pi_3\psi_1 + c\alpha_1\varphi_1\pi_3)^2 mm_t^2 + r\varphi_1^2 mm_t^2]/u_2\}\Delta NFA_t \\
&- \{[\beta(\pi_1 + \pi_3\psi_1 + c\alpha_1\varphi_1\pi_3)^2 mm_t MB_t + r\varphi_1^2 mm_t MB_t]/u_2\}\Delta mm_t \\
&- \{[\beta\pi_2(\pi_1 + \pi_3\psi_1 + c\alpha_1\varphi_1\pi_3)mm_t]/u_2\}\Delta p_{t-1} \\
&- \{[\beta c\alpha_1\varphi_2\pi_3(\pi_1 + \pi_3\psi_1 + c\alpha_1\varphi_1\pi_3)mm_t + r\varphi_1\varphi_2 mm_t]/u_2\}Y_{c,t-1} \\
&- \{[\beta c\alpha_1\varphi_3\pi_3(\pi_1 + \pi_3\psi_1 + c\alpha_1\varphi_1\pi_3)mm_t + r\varphi_1\varphi_3 mm_t]/u_2\}\Delta G_t \\
&- \{[\beta c\alpha_2\pi_3(\pi_1 + \pi_3\psi_1 + c\alpha_1\varphi_1\pi_3)mm_t]/u_2\}\Delta REER_{t-1} \\
&- \{[\beta\pi_3(\pi_1 + \pi_3\psi_1 + c\alpha_1\varphi_1\pi_3)mm_t]/u_2\}\Delta(r_t^* + E_t s_{t+1}) \\
&- \{[\delta\theta\eta(d_1 - 1)]/u_2\}\sigma_{r,t-1} \qquad \text{(A11b)}
\end{aligned}$$

where $u_2 = \beta[(\pi_1 + \pi_3\psi_1 + c\alpha_1\varphi_1\pi_3)mm_t]^2 + r\varphi_1^2 mm_t^2 + \delta\theta^2(d_1 - 1)^2 > 0$.

[20] Given that we need daily data to compute a reliable within-the-quarter volatility measure, we use bilateral US dollar rates.