An Estimation of the Effectiveness of China's Capital Controls and Sterilizations*

Abstract

In recent years, China has faced an increasing trilemma—how to maintain independent monetary policy and limit exchange rate flexibility simultaneously, while at the same time facing persistent and substantial international capital flows. This paper undertakes an empirical investigation to evaluate the effectiveness of China's sterilizations and capital mobility regulations, measured by the sterilization and offset coefficients respectively, using monthly data between mid 1999 and March 2009. We find that the effectiveness of China's sterilization is almost perfect in terms of the monetary base, while it is nearly half in light of M2, and the extent of China's capital mobility regulations still works but not well binds. Recursive estimation finds evidence of increasing mobility of capital flows and decreasing extent of sterilizations that may undercut China's ability to seek monetary autonomy and domestic currency stability simultaneously.

I. Introduction

The trilemma paradigm of open macroeconomics asserts that perfect capital mobility, fixed exchange rate and independent monetary policy cannot maintain simultaneously. In recent years, China has faced an increasing trilemma—attempting to pursue the stability of domestic currency and an independent monetary policy simultaneously, while at the same time facing substantial and persistent international capital flows with the aim to bet for profit of the RMB revaluation. As most developing countries did in 1980s, China addressed the trilemma by maintaining a combination of exchange rate stability and monetary independence, with strict capital controls. Whether China can maintain monetary autonomy depends on the effectiveness of its cross-border capital controls and sterilizations.

To mitigate the revaluation pressure of the RMB, Chinese authorities imposes stern capital controls on capital transactions, with the feature of encouraging capital outflows and discouraging capital inflows. However, capital controls become much more difficult when the economy is integrated with other economy and expanded in foreign trade (Fukao, 1990). Some studies have found that, in recent years, the effectiveness of China's capital control has, over time, diminished

and the restrictive system has become difficult to sustain, especially given the fact that current account convertibility, while bringing about massive efficiency gains, has also created numerous leakage and loopholes for illicit capital flows (Ma and McCauley, 2007, Yu, 2008, and Wang, 2009). The economic and social costs associated with continued draconian controls over capital movement have become ever larger and better recognized. In addition to imposing heavy administrative burden for the government, capital controls have caused distortion in investment decisions by Chinese enterprisers and household.

Moreover, it is increasingly difficult for China to implement sterilized operations when it holds huge international reserves and experiences large and persistent capital inflow. Due to the underdevelopment of financial market, Chinese authorities heavily depended on the two main sterilization measures--raising reserves requirements and issuing central bank bills (CBBs) to neutralize substantial capital inflow and resultant liquidity deluge. These sterilized operations and resultant accumulation of foreign reserves inevitably lead to large fiscal costs, financial repression and exchange risks. Even with massive sterilized interventions, Chinese economy overheating began to appear in 2006 and accelerated in 2007-08 due to capital inflow, featuring with commodities inflation, assets bubble, and excessive investments. China's rapid accumulation of international reserves and massive sterilizations has generated wide spread concerns. A mainstream view argues that while China has sterilized most of its past reserve increases, continuing to do so is becoming increasingly difficult (Prasad and Wei, 2005, Ouyang, Rajan and Willett, 2007, and Glick and Hutchison, 2009), and costs of the sterilizations grow rapidly, such as, fiscal cost, financial repression and foreign exchange risk (Greenwood, 2008, and Aizenman and Glick, 2008)**,** as its reserves continue to rise and capital controls become more ineffective. Therefore, Chinese authority can't maintain monetary independence and stability of domestic currency through capital transactions restrictions and massive sterilizations, under conditions of large and persistent capital inflow, and skyrocketing foreign reserves.

Against this background, this paper intends to estimate the effectiveness of China's recent sterilizations, as well as the degree of capital mobility regulations, measured by sterilization coefficient and offset coefficient respectively. The rest of the paper is organized as follows. Section II briefly explores the evolution of the balance of payments flows, international reserves accumulation and sterilization operations in recent China. Section III provides a brief analysis on the empirical methodology and the specified model used in this paper to estimate the sterilization and offset coefficients based on structural equations. Section IV discusses the data and definitions of variables to be used in the empirics. Section V analyzes the empirical results of the sterilization and offset coefficients based on monthly data for the period between mid 1999 and March 2009. The final section presents concluding remarks and policy implications for China.

## II. China's Capital Inflows, Reserves Accumulation and Sterilizations

1. Pattern of Balance of Payments Flows and Reserve Accumulation

China adopts the approach of selective easing of regulations to liberalize its international transactions. With liberalization of current transactions in 1996 and WTO entry in 2001, China's current account has been quite free. China implements a principle of general prohibition in capital transactions, with exception of freedom, and hence capital transactions are extensively regulated and authorization is awarded individually. With freedom in current transactions, there are potential channels that unwanted capital movements occur via current accounts, particularly when the authority imposed strict restrictions on capital flows (Fukao, 1990).

As seen in Figure 1, China has experienced increasingly large surplus in current balances and capital balances since 2001, and even the account of errors and omissions, which is often regarded as an approximate indicator of China's unrecorded capital movement, turned into positive in most of years during this period. The residual fluctuated sharply in response to market conditions, particularly the expectation on changes in the value of domestic currency[①].

[①]However, while often regarded as an indicator for unrecorded capital movements, errors and omissions should be interpreted with caution. In fact, the errors and omissions account could have captured valuation changes of the official foreign exchange reserves. When dollar falls against other major currencies, the value of foreign exchange reserves denominated in dollar will rise, hence leads to an errors and omissions inflow, and which has nothing to

Figure 1　China's Balance of Payment: 1990-2008　(in percent of GDP)
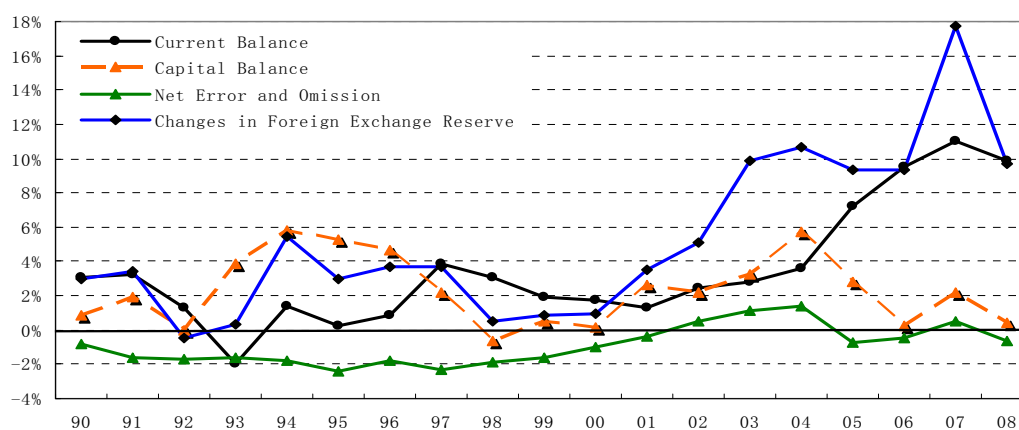
China has experienced a sharp increase in current surplus relative to the capital balance despite the one way revaluation anticipations on the RMB since the currency reform in 2005. It is somewhat hard to interpret the sharp increase in China's current surplus. It has been suggested by some observers that the current favorable balance has been partly driven by exports over-invoicing, imports under-invoicing, outflow payments of foreign investment income, and current transfers (Yu, 2008a, Ma and McCauley, 2007, and Ouyang, Rajan and Willett, 2007). On the other hand, the decline in the capital account surplus was mainly policy-driven. To mitigate revaluation pressure of the RMB, China's authority implemented the policy of "encouraging capital outflows and discouraging capital inflows". Chinese government has loosened a number of restrictions on capital outflows to stimulate outward investments by Chinese enterprises and domestic institutional investors. At the same time, the government tightened controls on capital inflows such as imposing a quota on offshore borrowing by foreign banks operating in China in July 2004 (Ouyang, Rajan and Willett, 2007).

Consequently, China's foreign exchange reserves increased substantially during this period. At the end of 2008, the amount of China's reserves skyrocketed at $1.95 trillion (now surpasses $2 trillion), is around two times as much as that of Japan, the traditionally largest foreign reserves holder. Obviously, China's huge reserves are always regarded as a sign that the RMB is seriously undervalued and will revalue significantly in the near future. With lessons from Asian financial crisis, large foreign reserves also tends to be viewed as an indicator of "strong fundamentals", hence leads to an upgrade of the country's credit ratings. This revaluation anticipation of the RMB (capital gains) and low risk perceptions motivated large-scale capital inflow into China and led to a rapid increase in foreign reserves as the People's Bank of China (PBOC) intervened in the foreign exchange market to purchase excess US dollar.

2. China's Sterilizations

It is sure that the official interventions will produce unavoidable impacts on China's monetary base and threat the independency of monetary policy. When the monetary authority purchases foreign exchange, the balance of foreign assets of the central bank rises initially, then the counterpart of the increase in foreign reserves is a corresponding growth in the deposits of commercial banks at the central bank. Therefore, official foreign exchange intervention changes the monetary base at the prevailing exchange rate. In order to restore the money supply partially or fully, the Chinese authority implemented some sterilized actions, such as, open markets operations (OMOs), reserves requirements and bank loan quota, to neutralize the capital inflows and maintain money supply unchanged. Owing to the limited depth and breadth of China's financial market,

do with capital inflows; while dollar appreciates, causing the dollar value of foreign reserve decline and capital outflows on the residual account.

two conventional sterilization policies frequently used by the PBC are issuing central bank bills and raising reserve requirements.

Issuing CBBs is a conventional sterilization operation frequently used by the PBOC. In early 1998, the PBOC used treasury bonds and securities as sterilization tool. Due to limited size of treasury bonds, the PBOC has replaced all outstanding securities with central bank bills for use in the open market operations since September 2002 (Ouyang, Rajan and Willet, 2007). The outstanding of CBBs had experienced rapid increase during the period of 2003-07, rising from RMB 165 billion in July 2003 to around RMB 4.3 trillion in August 2007, and to RMB 4.5 trillion in 2008. Since 2007, the issuance of the central bank bills had slowed down significantly, or even turned into negative for several months. The reasons for the slow down in issuance of CBBs can be probably attributed to growing fiscal burden induced by interest payments and banks' passive attitudes towards purchasing CBBs due to low yields.

Another important measure of sterilization is raising reserve requirements. Under conditions of large capital inflows and economic overheating in the period of 2006-08, reserve requirements had been frequent used by the PBOC as a main instrument to sterilize the excess liquidity. The legal reserves ratio of commercial banks had been raised continuously for 19 times from July 2006 to September 2008, rising from 8% to 17.5%. This led to sharp increase in the required reserve deposits of commercial banks in the central bank. The total increase in the reserve deposits amounted to RMB 5.43 trillion in this period, equaling to 41% of the stock of foreign reserves in 2008. This means that around 34% of increase in china's foreign reserves during this period was sterilized through raising reserve requirements, adjusted by the rapid growth in banks' deposits. Therefore, the instrument of raising reserve requirement has played the most important role in reducing money multiplier and neutralizing official intervention in China.

In addition, the PBOC has implemented administrative measures include window guidance to halt the non-government-approved construction loans and cool down specific sectors particularly the real estate industry, and other sterilized operations, such as, moral suasion and risk warnings, also have been frequently used to force commercial banks to maintain a reasonable credit growth with a upper limit.

III. Empirical Methodology and Model Specification

1. Empirical Methodology

There are a large number of empirical papers have studied central banks' policy responses to capital inflows and impacts of capital movements on domestic monetary and economic conditions. There are two basic approaches. One approach uses the structural equation initiated by Obstfeld(1982), many studies estimate a central bank's reaction function in which changes in the net domestic assets ($\triangle$NDA) are related to changes in net foreign assets($\triangle$NFA) and a set of control variables. The coefficient on $\triangle$NFA reflects effectiveness of sterilization. If it equals -1 means that the impact on monetary base of increases in net foreign assets (foreign reserves) is fully neutralized by a reduction of the same magnitude in net domestic assets, therefore the sterilization is complete. When the coefficient is zero, there is no sterilization at all, because a net increase in net foreign assets leads to a same amount of increase in reserved money (Ouyang, Rajan and Willett, 2007). Another approach uses VAR models to analyze the transmission of an impulse from changes in the net foreign assets to changes in the net domestic assets, domestic credit and aggregate money supply (Takagi and ESaka, 1999; He, Chu, Shu and Wong, 2005).

We follow the structural framework of Obstfeld (1982) and Ouyang, Rajan and Willett (2007), and examine the relationship between $\triangle$NFA and $\triangle$NDA, and $\triangle$M2 respectively. According to statistical reports of IMF's International Financial Statistics (IFS) and the PBOC, and the typical balance sheet of monetary authorities (Table 1), the sum of net foreign assets and net domestic assets is generally equals to reserved money or monetary base, namely $\triangle$NFA $+\triangle$NDA$=\triangle$MB. In some countries, such as Japan, the basic target of sterilization is to completely neutralize impact of changes in net foreign assets on MB ($\triangle$MB=0), and this indicates that the net domestic assets should change same amount as net foreign assets but in opposite direction.

<div align="center">Table 1 Balance Sheet of Monetary Authorities</div>

Assets	Liabilities and Equity
Foreign Assets (FA)	Currency in Circulation and Deposits/Reserved Money(MB)
Domestic Assets (DA)	Foreign Liabilities (FL)
Other Assets (OA)	Domestic Liabilities (DL)
	Other Liabilities (OL)
	Equity (K)

However, the Chinese monetary authority sterilizes impacts of increase in foreign exchange reserves not only on monetary base through undertaking open market operations, such as, issuing commercial papers, but also on aggregate money supply by changing money multiplier through raising reserves requirement ratio and conducting bank loans quotas. Thus, it is inappropriate to only measure sterilization effectiveness in terms of money base, and aggregate money M2 should be investigated. Consequently, in the case of $\triangle$M2, complete sterilization indicates that an increase in foreign assets is not associated with a corresponding increase in overall money supply.

The typical structural equations are as follows:

$$\Delta NFA_t = \alpha_0 + \alpha_1 \Delta NDA_t + \mathbf{X}_1' \boldsymbol{\alpha}_2 + u_t \tag{1}$$

$$\Delta NDA_t = \beta_0 + \beta_1 \Delta NFA_t + \mathbf{X}_2' \boldsymbol{\beta}_2 + v_t \tag{2}$$

$$\Delta M2_t = \gamma_0 + \gamma_1 \Delta NFA_t + \mathbf{X}_2' \boldsymbol{\gamma}_2 + \varepsilon_t \tag{3}$$

where equation (1) and (2) are functions of balance of payment, and equation (3) is the monetary reaction function, ΔNFA and ΔNDA represent change in net foreign assets (foreign exchange reserves) and net domestic assets (domestic money creation) respectively. Both $\mathbf{X}_1$ and $\mathbf{X}_2$ are vectors of control variables. α_1 is the offset coefficient. $\alpha_1 = 0$ represents no capital mobility, while $\alpha_1 = -1$ implies perfect capital mobility. β_1 is sterilization coefficient. $\beta_1 = -1$ means international reserves buildup is perfectly sterilized, and $\beta_1 = 0$ represents the monetary authority doesn't sterilize at all. Thus, $\alpha_1, \beta_1 \in [-1,0]$.

When $\Delta M2$ is used instead of ΔNDA in equation (3), $\gamma_1 = 0$ represents complete sterilization because a rise in foreign exchange reserves doesn't lead to increase in the broad money, while $\gamma_1 = 1$ implies no sterilization. Actually, the sterilization coefficient γ_1 should be called "non-sterilization coefficient" in terms of M2. Therefore, a small offset coefficient and a large sterilization coefficient generally implies that capital mobility regulation and sterilization is effective, and hence the central bank has fairly high independence in monetary policy to neutralize capital inflows on a sustainable base.

2. Model Specification

Based on the framework of Ouyang, Rajan and Willett (2007), we specify equations as follows:

$$\Delta NFA_t^* = \alpha_0 + \alpha_1 \Delta NDA_t^* + \alpha_2 \Delta LMM_{t-i} + \alpha_3 \Delta LP_{t-i} + \alpha_4 \Delta RR_{t-i} + \alpha_5 y_{ct-i}$$
$$+ \alpha_6 \Delta LREER_{t-i} + \alpha_7 FXFS_{t-i} + \alpha_8 \Delta Li_{\$t-i} + u_t \tag{4}$$

$$\Delta NDA_t^* = \beta_0 + \beta_1 \Delta NFA_t^* + \beta_2 \Delta LMM_{t-i} + \beta_3 \Delta LP_{t-i} + \beta_4 \Delta RR_{t-i} + \beta_5 y_{ct-i}$$
$$+ \beta_6 \Delta LREER_{t-i} + \beta_7 FXFS_{t-i} + \beta_8 \Delta Li_{\$t-i} + \beta_9 \Delta LSP_{t-i} + \beta_{10} G_{t-i} + v_t \tag{5}$$

$$\Delta M2_t^* = \gamma_0 + \gamma_1 \Delta NFA_t^* + \gamma_2 \Delta LMM_{t-i} + \gamma_3 \Delta LP_{t-i} + \gamma_4 \Delta RR_{t-i} + \gamma_5 y_{ct-i}$$
$$+ \gamma_6 \Delta LREER_{t-i} + \gamma_7 FXFS_{t-i} + \gamma_8 \Delta Li_{\$t-i} + \gamma_9 \Delta LSP_{t-i} + \gamma_{10} G_{t-i} + \varepsilon_t \tag{6}$$

where $i = 0,1,\cdots n$. ΔNFA^*, ΔNDA^* and $\Delta M2^*$ are changes in the adjusted net foreign assets, adjusted net domestic assets (adjustments will be discussed in the next section) and M2 scaled by the GDP respectively. ΔLMM represents change in money multiplier for M2. ΔLP is inflation

rate. ΔRR indicates change in legal reserve requirement ratio. y_c is cyclical output. $\Delta LREER$ is change in real effective exchange rate. $FXFS$ represents the forward-spot exchange rate spread of the RMB against the dollar. $\Delta Li_\$$ is change in time deposit rate of Eurodollar[①]. ΔLSP is change in China's A-share stock market index. G is the share of government's deficits in the GDP.

As seen in the Equation 4, the balance of payments function consists of seven control variables. We expect these variables influence the adjusted net foreign assets in the following ways: First, a rise in M2 money multiplier will increase supply of aggregate money and push interest rate down, hence capital inflows decrease. In addition, the rise in money multiplier will induce the monetary authority to tighten restrictive measures towards bank credit and capital inflows. Second, higher inflation rate increases investors' concerns on the depreciation of domestic currency and the rise in interest rate, which will lead to decline in assets price and capital losses, and hence a reduce in capital inflows. Third, the rise in reserve requirements will cause an increase in domestic interest rate and provide an incentive for capital inflows. Fourth, a domestic boom in output will worsen the current account and reduce international reserves through income effect. However, domestic prosperity will strengthen confidence of foreign investors and encourage capital inflows. Thus, higher real output has a double-sword effect on capital inflows. Fifth, a rise in real effective exchange rate leads to double impacts on capital mobility. The appreciation of domestic currency not only causes a worse in current balance, but also strengthens further appreciation expectation in turn encourages capital inflows, hence the impact of changes in real effective exchange rate on net foreign assets is undetermined. Sixth, the larger in the exchange rate spread between forward and spot of the RMB against the dollar, the stronger in the pressure of appreciation (depreciation) of the domestic currency, and there are more foreign capital will flow in (out). Seventh, increase in the interest rate of the Eurodollar will discourage capital inflows.

As Equation 5 shows, the monetary policy function consists of nine control variables that are considered to probably important factors impacting monetary actions. The Chinese monetary authority generally conducts contractionary monetary policy in response to a rise in inflation, domestic economic boom, a rise in money multiplier and expected exchange rate depreciation, hence, the expected coefficient for the above variables should be negative. Specifically, these variables impact the adjusted net domestic assets through the following ways: First, the impact of rise in money multiplier on the net domestic assets depends on the type of monetary authority's contractionary measures. When the authority uses open market operations measures to offset increase in money multiplier, the size of net domestic assets will decrease. When the authority implements measures of reserve requirements to reduce money multiplier directly, the amount of net domestic assets probably increases. Therefore, change in money multiplier produces double-sword effects on the net domestic assets, and a rise in reserve requirements makes domestic assets increase. Second, a rise in real GDP growth rate above the trend will lead to a contractionary policy response and hence expected coefficient is negative. Third, an increase in the real effective exchange rate and the RMB revaluation pressure will force the authority implement expansionary monetary policy, hence, the expected coefficient of the REER and the forward-spot exchange rate spread is positive and negative respectively. Fourth, a rise in the deposit rate of Eurodollar discourages capital inflows and the net domestic assets tend to fall. Lastly, increase in assets prices generally induces the authority's contractionary policy response, particularly under circumstances of assets bubble.

When $\Delta M2^*$ is used instead of ΔNDA^* in Equation 6, some changes in coefficients of control variables will occur correspondingly. First, a rise in the domestic economic boom, such as, higher inflation rate, higher real output growth above the trend and higher stock price index generally engenders the monetary authority's contractionary policy actions, hence expected coefficients of these variables are negative. Second, maintaining stability of exchange rate is an important target of Chinese monetary authority, therefore, a decrease in the interest rate in Eurodollar, an appreciation in the real effective exchange rate and an increase in revaluation expectation on

---

[①]Theoretically, the interest rate spread between the RMB and the dollar is a better variable comparing to the time deposit interest rate of the dollar. However, due to the still largely regulated interest rate of the RMB by the government and the relatively effective in the controls on cross-border capital movements, the coefficients of the interest rate spread in the regression equations are often insignificant or have wrong direction. Therefore, we use interest rate of the dollar instead of the interest rate spread between the two currencies.

domestic currency, generally cause the authority to implement loose monetary policy to mitigate revaluation pressure, and hence leads to increase in aggregate money supply. Third, a rise in aggregate money supply generally accompanies with increase in government fiscal deficits, because the authority has to finance the government expenditure through increasing money supply.

IV. Variables and Data

Our estimations are based on monthly data over the sample period from 1999:6 to 2009:3. Most of data come from the CEIC database, the rest data are from other sources. For example, reserve requirements data comes from the PBOC, three month RMB non-deliverable forward rate (NDF) against the dollar is from the Bloomberg, and real effective exchange rate of the RMB come from the Bank of International Settlement (BIS). Table 2 summarizes definitions and measurements of various variables in the estimated equations. The definitions, measurements and adjustments of these variables are discussed as follows.

The dependent variables, such as the changes in the adjusted ΔNFA^*, ΔNDA^* and $\Delta M2^*$, are scaled by the monthly GDP. The monthly GDP is measured by distributing quarterly GDP into corresponding three months weighted by the ratio of industrial value added. We can directly obtain the data on China's foreign exchange reserves and its foreign liabilities from the PBOC, hence we can easily get the data on the net foreign assets. However, it is worthy of noting that some components of foreign exchange reserves accumulation are not associated with corresponding changes in monetary base, such as exchange rate fluctuation and investment interest income. Therefore, we should exclude the non-policy related changes in the NFAs due to revaluation effects and interest income.

Although there are no officially released data about currency composition of China's international reserves, a public accepted view think that the share of dollar assets should reach, or even surpass 80%. To simplify, we suppose that all of China's foreign assets are invested in dollar assets[1]. The change in net foreign assets due to the revaluation effect is:

$$RE_t = NFA_{t-1}(\frac{e_t - e_{t-1}}{e_{t-1}}) \tag{7}$$

where e_t is the average exchange rate the RMB against the dollar at time t.

---

[1]We also suppose that China's foreign assets consist of the dollar, euro and yen assets, and their shares are 80%, 15% and 5% respectively. We find that there just existed small difference in the value of foreign exchange reserves among different assumptions about the international reserves structure.

Table 2　Definitions and Measurements of the Variables

Variables	Definitions	Measurements
NFA	Foreign reserves denominated in domestic currency minus foreign liabilities.	Foreign exchange (assets)－ Foreign liabilities
$\triangle$NFA*	The change in NFA excluding revaluation effect and interest income scaled by the monthly GDP.	$\dfrac{\Delta[NFA_t-(\frac{e_t-e_{t-1}}{e_{t-1}})NFA_{t-1}-\frac{i_{TBt}}{12}(\frac{NFA_t+NFA_{t-1}}{2})]}{GDP_t}$
$\triangle$NDA*	The change in (net domestic assets + net other assets – capital item) + revaluation effect + interest income scaled by the GDP.	$\dfrac{\Delta MB_t}{GDP_t}-\Delta NFA_t^*$
$\triangle$M2*	The change in M2 scaled by the monthly GDP.	$\dfrac{\Delta M2_t}{GDP_t}$
$\triangle$LMM	The change in money multiplier (MM) for M2 (MM= M2/Monetary Base).	$\ln(MM_t)-\ln(MM_{t-1})$
$\triangle$LREER	The change in the real effective exchange rate (REER).	$\ln(REER_t)-\ln(REER_{t-1})$
$\triangle$RR or $\triangle$LRR	The change in commercial banks' reserve requirement ratio.	RR_t-RR_{t-1} or $\ln(RR_t)-\ln(RR_{t-1})$
$\triangle$LP	The change in CPI index P (inflation rate).	$\ln P_t-\ln P_{t-1}$
FXFS	The average spread between 3-month NDF forward rate (F_{NDF}) and spot rate (S) of RMB against the dollar.	$\dfrac{\ln F_{NDFt}-\ln S_t}{\ln S_t}$
$\triangle$Li$_\$$	The change in six-month Eurodollar deposit rate.	$\ln(i_{\$t})-\ln(i_{\$t-1})$
$\triangle$LSP	The change in the stock index of Shanghai Composite (SP) or yields of stock investment.	$\ln(SP_t)-\ln(SP_{t-1})$
y_c	Cyclical income. The monthly real output deviates from its trend (GDP^T) scaled by the HP-filter output trend.	$\dfrac{GDP_t-GDP_t^T}{GDP_t^T}$
G	The share of the government's deficits in the monthly GDP.	Government deficits/GDP

Assuming all of China's international reserves are invested in US ten-year treasury bonds, hence the interest yield of international reserves at month t is:

$$yd_t=\frac{i_{TBt}}{12}\frac{NFA_{t-1}+NFA_t}{2} \qquad (8)$$

where i_{TB} is interest rate of US ten-year nominal interest rate.

If we subtract equation (7) and (8) from the NFA, and scaled by the monthly GDP, then the adjusted NFA can be obtained as following:

$$NFA_t^*=\frac{NFA_t-RE_t-yd_t}{GDP_t}=\frac{NFA_t-NFA_{t-1}(e_t/e_{t-1}-1)-i_{TBt}(NFA_{t-1}+NFA_t)/24}{GDP_t} \qquad (9)$$

According to the formula $MB=NFA+NDA$, the adjusted NDA can be written as:

$$NDA_t^*=MB_t/GDP_t-NFA_t^* \qquad (10)$$

Changes in NFA_t^* and NDA_t^* will be used as dependent variables in Equation (4) and (5) respectively. Another dependent variable, the change in $M2_t^*$ will be used in Equation (6) can be expressed as $M2_t$ scaled by the monthly GDP_t, namely $M2_t^* = M2_t / GDP_t$.

Regarding the control variable of cyclical income (y_c), we use the Hodrick-Prescott (HP) Filter method to measure trend of real GDP. The Hodrick-Prescott Filter is a smoothing method that is widely used among macroeconomists to obtain a smooth estimate of the long-term trend component of a series. If we suppose GDP^T is the HP trend of the output, hence cyclical income scaled by long-term trend of real GDP can be expressed as $y_c = (GDP - GDP^T)/GDP^T$. The other various control variables are listed clearly with definitions and measures in the Table 2, it is not necessary to explain them in detail further.

V. Empirical Results

We use the method of Ordinary Least Squares (OLS) to estimate the equation (4), (5) and (6). The estimation process consists of three steps: First, conducting Augmented Dickey-Fuller (ADF) unit root test to check for stationery to all variables. Second, setting up structural regression equations and estimating these equations. Finally, applying various tests to the estimated equations and evaluating their quality, such as, the autocorrelation and heteroskedasticity test, the CUSUM test and the Chow breakpoint test.

1. ADF Test

To avoid the problem of "Spurious Correlations", it is necessary to conduct stationary test before estimating the OLS equations. We apply the standard ADF unit root test to each of variables with the lag length of the ADF test equation decided by the Schwartz Information Criterion (SIC) or Akaike Information Criterion (AIC). The ADF test results are listed in the Table 3. As the Table shows, all variables are stationary at 5 percent significant levels.

2. The Balance of Payment Function △NFA*

The estimated balance of payment function is as the following:

$$\Delta NFA_t^* = \underset{(10.5)}{0.0562} - \underset{(-7.36)}{0.3022}\Delta NDA_t^* - \underset{(-6.00)}{0.3431}\Delta LMM_t - \underset{(-2.12)}{1.6281}\Delta LP_{t-4} + \underset{(2.00)}{0.0319}\Delta RR_{t-1}$$
$$- \underset{(-3.76)}{2.3684}y_{ct-2} + \underset{(3.74)}{1.1339}\Delta LEER_{t-4} - \underset{(-2.83)}{0.6948}\Delta LEER_{t-6} - \underset{(-2.00)}{2.7752}FXFS_t - \underset{(-4.32)}{5.1583}FXFS_{t-12} \quad (11)$$

where R^2=0.655, $\overline{R}^2 = 0.622$ and DW=2.10. The statistics magnitudes in brackets of the equation are t statistics (same hereafter). The results of the Correlogram-Q-statistics test and the Auto-regressive conditional heteroskedasticity (ARCH) LM test to residuals of the equation show that the residual series has no autocorrelation, partial correlation and heteroskedasticity. The CUSUM tests find that both the cumulative sum statistic and the cumulative sum of squares statistic go inside the area between two 5% critical lines, and which is suggestive of coefficients, parameters or variances stability respectively.

Table 3 ADF Unit Roots Test for China's Data: 1999:6-2009:3

Variables	Type of Test (c, t, n)	ADF Test Statistic H_0:Variable has a unit root	Test Result
$\triangle$NFA*	(c,0,1)	-3.60***	I(0)
$\triangle$NDA*	(c,0,0)	-10.9***	I(0)
$\triangle$M2*[①]	(c,0,0)	-11.1***	I(0)
$\triangle$LMM	(c,0,0)	-13.7***	I(0)
$\triangle$LREER	(c,0,0)	-11.3***	I(0)
$\triangle$RR	(c,t,0)	-1.95**	I(0)
$\triangle$LRR	(c,0,0)	-9.30***	I(0)
$\triangle$p	(c,0,0)	-8.38***	I(0)
FXFS	(0,0,0)	-2.11**	I(0)
$\triangle$Li$_\$$	(c,0,0)	-6.04***	I(0)
$\triangle$LSP	(c,0,1)	-5.35***	I(0)
y_c	(c,0,12)	-4.48***	I(0)
G	(0,0,12)	-1.95**	I(0)

Note: "c", "t" and "n" designates intercept, trend and lag length respectively. "*", "**", and "***" denotes the ADF test statistic is significant at 10%, 5% and 1% respectively.

①The sample range of $\triangle$M2* is 1999:6-2008:12. $\triangle$M2* is not stationary in the sample of 1999:6-2009:03.

As seen in Equation 11, the estimated offset coefficient is around 0.30 and statistically significant[①], indicating a fairly large degree of capital mobility despite China's capital controls[②]. The money multiplier, inflation and reserves requirements are statistically significant with correct estimated signs, suggesting that a rise in money multiplier and reserves requirement and a fall in inflation rate leads to an increase in interest rate and foreign capital inflow. The lagged cyclical output is statistically significant and negative, which means that the income effect causing a worse in current account probably outweighs the impact that positive cyclical output on attracting foreign capital. The coefficients of the spread of NDF forward and spot exchange rate are statistically significant and economically negative, suggesting expectation on the RMB revaluation produces a strong impact on capital inflow. The different sign of the lagged REER term in different period shows that appreciation of the domestic currency produces double-sword effects on cross-border capital mobility, and its positive impact on capital inflows through strengthening appreciation expectation is probably larger than negative effect on current balance under China's recent gradual appreciation policy.

[①]The offset coefficient that Ouyang, Rajan and Willett (2007) estimated was much larger and reached around 0.63 to 0.70, reflecting that a substantial degree of capital movement and the high ineffectiveness in China's capital controls. In consideration into China's current strict restrictions on capital transactions, the author thinks that the value of 0.30 for offset coefficient is probably more credible.

[②]The effectiveness of China's capital controls can also be observed in differentials between onshore RMB interest rates and offshore RMB (EuroRMB) interest rates. Due to china's strict capital controls and the internationalization process of RMB just started, the data on offshore interest rates can't be available. Borrowed from the approach of Fukao(1990), we estimated the RMB offshore interest rate by three-month Eurodollar rate and three-month spot-forward spread of RMB-dollar exchange rate on the Hong Kong NDF foreign exchange market. We found that there existed persistent and large differentials between three-month RMB interest rates onshore and offshore, which reflects that China's capital control is still binding. However, due to the fact that there is still lack of well-functioned money and capital markets in China, we should be cautious to judge the effectiveness of China's capital restrictions by interest rates spread. In sum, the persistence of sizeable onshore-offshore yield gaps proves that China's capital control is at least partially effective (see Wang, 2009).

3. The Monetary Reaction Function △NDA*

(1) Complete Sample 1999:06-2009:03
The estimated monetary reaction function can be written as following:

$$\Delta NDA_t^* = \underset{(4.25)}{0.0380} - \underset{(-10.7)}{0.9620}\Delta NFA_t^* - \underset{(-14.7)}{0.8855}\Delta LMM_t + \underset{(9.07)}{0.6501}\Delta LMM_{t-12} + \underset{(1.79)}{0.0324}\Delta RR_{t-1}$$

$$+ \underset{(2.30)}{3.1251}y_{ct} - \underset{(-3.58)}{4.9319}y_{ct-1} + \underset{(1.75)}{1.2994}y_{ct-4} + \underset{(3.17)}{1.0795}\Delta LREER_{t-4} - \underset{(-5.59)}{9.8483}FXFS_{t-12} \quad (12)$$

$$- \underset{(-2.35)}{0.1449}\Delta Li_{\$t} + \underset{(13.5)}{0.6832}\Delta NDA_{t-12}^* - \underset{(-2.50)}{0.0911}\Delta NDA_{t-16}^*$$

where R^2=0.911, $\bar{R}^2 = 0.898$ and DW=1.68. The residual tests show that the residual series from the estimated equation has no autocorrelation and partial correlation but heteroskedasticity, and the cumulative sum of squares statistic moves outside the area between the two critical lines, and which is suggestive of parameters or variances instability.

As Equation 12 shows, the estimated sterilization coefficient is statistically significant and is around 0.96, indicating that Chinese monetary authority has massively sterilized the accumulation of foreign exchange reserves in recent years. The opposite sign between money multiplier and lagged term shows that its increase has no certain but generally negative impact on monetary base. To maintain stability of aggregate money supply is an important target for Chinese monetary policy, the authority can reduce monetary base by conducting open market operations or reduce money multiplier through raising reserves requirements. Cyclical output and its lagged terms produce undetermined but generally negative impacts on monetary base, because the authority tends to conduct contractionary policy to address economic overheating, hence the money base and net domestic assets decrease. The significantly positive sign of the reserves requirements indicates that its increase certainly leads to a rise in monetary base. The lagged REER term has positive sign reflects that the authority generally carries out expansionary monetary policy to mitigate the appreciation pressure of the currency by reducing interest rate. The significantly positive sign of the forward-spot spread shows that revaluation expectation attracts capital inflow and leads to increase in monetary base. The significantly negative sign of the Eurodollar interest rate suggests that a rise in yields of foreign assets will attract capital to move out, hence leads to decrease in the dollar purchase and monetary base.

The instability of the monetary reaction function is probably attributed to the structural changes. During the sample period, the amount and structure of China's capital movements has changed fundamentally. The Chow break point test shows that there existed a break point at the point of September 2003. Hence, we divide the sample of 1999:06-2009:03 into two sub-samples with the ranges of 1999:06-2003:08 and 2003:09-2009:03 respectively.

(2) Sub-sample 1999:06-2003:08
The estimated monetary reaction equation with the sub-sample of 1999:06-2003:08 is the following:

$$\Delta NDA_t^* = \underset{(1.15)}{0.0094} - \underset{(-4.52)}{0.6419}\Delta NFA_t^* - \underset{(-11.9)}{0.8065}\Delta LMM_t + \underset{(14.4)}{1.0422}\Delta LMM_{t-12} - \underset{(-2.33)}{1.6326}y_{ct-6} \quad (13)$$

$$- \underset{(-3.30)}{0.2525}\Delta Li_{\$t-11} + \underset{(20.7)}{0.8701}\Delta NDA_{t-12}^* - \underset{(-3.73)}{0.1465}\Delta NDA_{t-16}^*$$

where R^2=0.959, $\bar{R}^2 = 0.947$ and DW=2.33. The residual tests show that the residual series has no autocorrelation, partial correlation and heteroskedasticity, and the CUSUM tests suggest the stability of the equation in coefficients, parameters and variances.

As seen in Equation 13, the estimated sterilization coefficient is also statistically significant and is around 0.64, suggesting that the PBOC had conducted moderate neutralization during the period of 1999:06-2003:08, and which is suit to the moderate capital inflows in this period. The money multiplier and its lagged term generally produce negative impact on monetary base. The coefficient of the cyclical output is significantly negative, indicating that the authority generally has the intention to conduct contractionary monetary policy to address economic overheating. The Eurodollar interest rate has correct sign.

(3) Sub-sample 2003:09-2009:03

The estimated monetary reaction function with the sub-sample of 2003:09-2009:03 can be written as the following:

$$\Delta NDA_t^* = \underset{(3.39)}{0.0608} - \underset{(-9.72)}{0.9709}\Delta NFA_t^* - \underset{(-14.4)}{1.0101}\Delta LMM_t + \underset{(6.38)}{0.5272}\Delta LMM_{t-12} + \underset{(1.98)}{0.4809}\Delta LRR_{t-11}$$

$$+ \underset{(2.13)}{3.7446}\,y_{ct} - \underset{(-3.17)}{5.4450}\,y_{ct-1} + \underset{(1.98)}{2.0417}\,y_{ct-4} + \underset{(3.89)}{1.5871}\Delta LREER_{t-4} - \underset{(-1.91)}{4.5971}\,FXFS_{t-11} \qquad (14)$$

$$- \underset{(-3.28)}{0.2570}\Delta Li_{\$t} - \underset{(-1.98)}{0.1592}\Delta LSP_{t-6} + \underset{(9.67)}{0.5832}\Delta NDA_{t-12}^*$$

where R^2=0.930, $\bar{R}^2 = 0.915$ and DW=1.65. The residual series has no autocorrelation, partial correlation and heteroskedasticity, and the equation is stable in coefficients, parameters and variances.

The estimated sterilization coefficient is statistically significant and is around 0.97, with an increase of 51% in comparison to the preceding sample period, indicating that the Chinese authority had conducted massive sterilization under the background of large and persistent capital inflows during the period of 2003:09-2009:03. The negative lagged stock price index indicates that the authority tends to implement contractionary policy to mitigate the upward pressure on asset prices particularly under the backdrop of asset bubbles. The cyclical output, money multiplier and their lagged terms generally produce negative impacts on monetary base and the NDAs. The coefficients of the rest control variables and its lagged terms are statistically significant with correct signs.

4. The Monetary Reaction Function △M2*

The estimated monetary reaction function with △M2* as the dependent variable can be expressed as the following:

$$\Delta M2_t^* = \underset{(4.43)}{0.1636} + \underset{(3.90)}{0.5698}\Delta NFA_t^* - \underset{(-1.92)}{0.0703}\Delta RR_{t-3} - \underset{(-2.33)}{3.0128}\,y_{ct} + \underset{(3.89)}{1.5871}\Delta LREER_{t-4}$$

$$- \underset{(-2.64)}{10.143}\,FXFS_{t-2} - \underset{(-1.78)}{2.3061}\Delta LP_{t-1} - \underset{(-3.21)}{0.3671}\Delta Li_{\$t-1} - \underset{(-2.13)}{0.2745}\Delta LSP_{t-12} + \underset{(1.70)}{1.6861}\,G_{t-2} \qquad (15)$$

$$- \underset{(-2.40)}{0.2228}\Delta M2_{t-1}^* + \underset{(2.93)}{0.2705}\Delta M2_{t-3}^*$$

where R^2=0.390, $\bar{R}^2 = 0.324$ and DW=2.03. The residual tests show that the residual series has no autocorrelation, partial correlation and heteroskedasticity, and the CUSUM tests suggest the stability of the equation in coefficients, parameters and variances.

As seen in Equation 15, the estimated non-sterilization coefficient is significantly positive and is around 0.57, indicating that a unit rise in the international reserves leads to around 0.57 unit increase in M2, the aggregate money supply, hence the share of sterilization of the accumulation just reached 43%. Therefore, although Chinese authority had implemented many policies even administrative measures to neutralize accumulation of international reserves in the sample period of 1999:09-2008:12, the effectiveness of Chinese sterilization policy is quite limited in term of M2.

The coefficient of the government deficit is significantly positive, suggesting that the authorities are forced to expand aggregate money supply to provide a funding source for increase in government expenditures. The significantly negative sign of the reserve requirement ratio means that a rise in its value certainly leads to a decrease in the aggregate money supply. The coefficients of the inflation, stock price and cyclical output (domestic economic boom) are significantly negative, suggesting the authority tends to implement contractionary monetary policy by reducing money supply when the economy shows some signs of overheating in commodities, assets and real economy. The coefficients of the forward-spot exchange rate spread, real effective exchange rate and Eurodollar interest rate are statistically significant with correct signs.

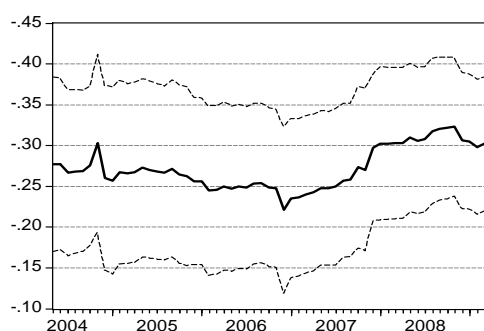## 5. Estimated Recursive Offset and Sterilization Coefficients

The method of recursive coefficients estimation is often used to check for stability of the estimated equation, and the stability of the equation depends on stability of recursive coefficients. In addition, w can apply the method of recursive estimation to estimate dynamic evolution of offset and sterilization coefficients (Figure 2).

As seen in Figure 2a, the recursive offset coefficient remained fairly stable between early 2005 and mid-2007 at around 0.25 before rising rapidly from hereafter to an average of about 0.32 in 2008, indicating that capital mobility increased significantly in the latter period. As Figure 2b-c shows, there existed an obvious structural change in the recursive sterilization coefficient. During the sub-sample period from early 2002 to mid-2003, the degree of sterilization had remained fairly stable and fluctuated around a relatively low level of 0.60. However, the sterilization coefficient had rose sharply and fluctuated around 1.05 in the period between late 2003 and 2007, indicating that the authority had over-sterilized accumulation of international reserves. Since early 2008, the sterilization degree began to decrease moderately and maintained at around 0.95 at the end of March 2009.

In the case of M2, the non-sterilization coefficient increased fairly rapidly, rising from around 0.30 in the period of 2004-06 to about 0.40 in 2007 and 0.50 in 2008, which suggests that the degree of sterilization decreased from around 0.70 in 2005 to about 0.50 in 2008. The rise in the offset coefficient and decrease in the sterilization degree reflects that the independency of China's monetary policy has decreased over time. Therefore, it is increasingly difficult for Chinese authority to maintain independent monetary policy through sterilizing large and persistent capital inflows under the backdrop of large capital inflow and skyrocketing international reserves.

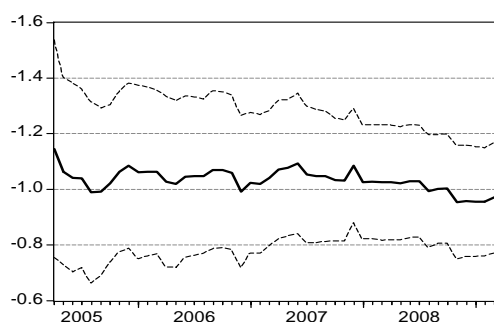Figure 2 Estimated Recursive Offset and Sterilization Coefficients
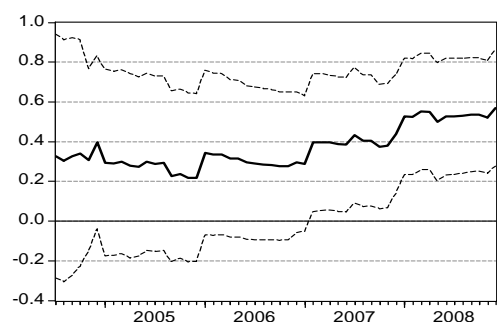a. Offset Coefficient   b. Sterilization Coefficient: 1999:06-2003:08
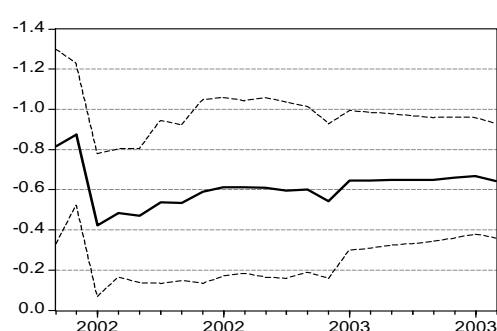
c. Sterilization Coefficient: 2003:09-2009:03   d. Non-sterilization Coefficient

VI. Conclusion

Our empirical results indicate that the degree of China's cross-border capital movement has increased moderately in recent years, the offset coefficient rising from around 0.25 in 2005 to above 0.30 in 2008. This is consistent with some scholars' judgments on China's capital controls have been becoming less binding (Ma and McCauley, 2005; Prasad and Wei, 2005). However, the increased capital inflows and international reserves had been nearly completely sterilized, or even

over-sterilized in term of the monetary base, and hence it seems that the gradual rise in extent of capital movement hasn't undermined independency of China's monetary policy. But at the same time, we find that sterilization effectiveness is quite poor if we examine the non-sterilization coefficient in light of M2, nearly more than a half increase in foreign reserves hasn't been sterilized. Comparing to open market operations, administrative sterilization measures, such as, reserves requirements and banks loan quota, are more heavily used by Chinese authorities. Therefore, the sterilization coefficient of M2 rather than the monetary base is probably a better indicator to evaluate effectiveness of sterilization. This can partly explain China's latest occurred commodities inflation, assets bubble and economic overheating.

With the decreasing effectiveness of China's capital mobility regulations and sterilizations, it is increasingly difficult for Chinese authorities to maintain the stability of domestic currency and monetary autonomy simultaneously, when it faces persistent and substantial international capital inflows. As a large and relatively closed economy, it was impossible to abandon independent monetary policy as a macroeconomic instrument, China should choose an independent monetary policy rather than a fixed exchange rate regime. To address the trilemma smoothly, Chinese authorities should continue to relax the management of the exchange rate, in addition to taking further steps towards deregulation of capital outflows. More flexibility in the RMB exchange rate can lead to rise in the exchange rate risk and discourage the movements of speculative capital, which in turn should provide the PBOC greater opportunities to use interest rate policy to manage domestic liquidity and economic conditions.

References

Aizenman J. and Glick R. "Sterilization, Monetary Policy, and Global Financial Integration", NBER Working Paper 13902, March 2008.

Fukao M. "Liberalization of Japan's Foreign Exchange Controls and Structural Changes in the Balance of Payments", *Monetary and Economic Studies*, Vol.8(2), September 1990, pp.101-165.

Glick R. and Hutchison M. "Navigating the Trilemma: Capital Flows and Monetary Policy in China", *Journal of Asian Economics*, Vol. 20, 2009, pp.205–224.

Greenwood J. "The costs and Implications of PBC Sterilization", *The Cato Journal*, March 2008.

He Dong, Chu Carmen, Shu Chang and Wong Amy. "Monetary Management in mainland China in the Face of Large Capital Inflows", Hong Kong Monetary Authority, Research Memorandum 07/2005, April 2005.

Ma Guonan and McCauley R. "Do China's Capital Controls still Bind? Implications for Monetary Autonomy and Capital Liberalization", BIS Working Papers No. 233, August 2007

Obstfeld M. "Can We Sterilize? Theory and Evidence", *AEA Papers and Proceedings, May 1982,* pp.45-50.

Ouyang A., Rajan R. and Willett T. "China as a Reserve Sink: The Evidence from Offset and Sterilization Coefficients", Hong Kong Institute for Monetary Research (HKIMR) Working Paper No.10/2007, May 2007.

Prasad E. and Wei Shangjin. "Understanding the Structure of Cross-border Capital Flows: The Case of China", December 2005.

Takagi S. and Esaka T. "Sterilization and the Capital Inflow Problem in East Asia, 1987-97", Discussion Paper No. 86, Economic Research Institute, Economic Planning Agency, Japan, August 1999.

Wang Yongzhong. "Liberalization of Foreign Exchange Controls: Japan's Experience and Its Implications for China", Nikkei Asia Scholarship Research Report, Japan Center for Economic Research, November 2009.

Yu Yongding. "Managing Capital Flows: the Case of China", Research Center for International Finance, Institute of World Economics and Politics, CASS, Working Paper No.0816, September 2008.