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Monetary policy transmission with two exchange rates and a single currency: The Chinese experience

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Abstract

In emerging market economies, transmission of monetary policy through the foreign exchange market is complicated by the coexistence of financial restrictions and arbitrages. Using China as an example, we show that the coexistence of exchange rate interventions, capital controls and an onshore-offshore exchange rate differential makes the long run equilibrium in the currency market nonlinear. Disturbances to this nonlinear long run equilibrium could offset the impact of monetary policy actions on domestic price stability. Omitting such nonlinearity leads to biased inference on the effectiveness of monetary policy.

Keywords: CNY, CNH, monetary policy, capital controls
JEL classification: E52, F31, F40

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1 Introduction

Increased participation of emerging market countries in the global financial market has sparked strong interest among international macroeconomics researchers. Compared to developed economies, the issues of financial repression and vulnerability to international economic shocks loom larger in emerging market economies and complicate efforts of policymakers to transmit monetary policy via the exchange rate channel.

Frankel (2010) notes that the literature commonly distinguishes emerging market economies from advanced economies in terms of their imperfect financial sectors, capital controls and opportunities for international arbitrage. Unlike advanced economies, international financial market arbitrage is usually unobserved in emerging market countries. Without this data, it is challenging to understand these important, and potentially costly, issues.

The emergence of China's renminbi (RMB) offshore market provides a unique opportunity to explore this monetary policy challenge in an emerging-country context. China's rapid economic growth amplifies its economic impact on the rest of the world and raises the importance of its currency in international transactions. The latest BIS triennial central bank survey (BIS, 2016) finds that the daily average turnover of RMB transactions increased from almost nothing in 2007 to $202 billion in April 2016. The survey further mentions that by April 2016 the RMB accounted for roughly 4% of global foreign exchange transactions, making it the world's eighth-most traded currency.

This rising RMB transaction volume has created a huge offshore RMB market. However, due to the existence of capital controls and currency market interventions in the onshore RMB market, there are usually gaps between the offshore (CNH) rate and onshore RMB (CNY) rate. An arbitrage business thus sprung up has around the differentials in the CNY-CNH exchange rate. In this paper, we study China's monetary policy transmission in the context of the RMB, a currency with two exchange rates.[1]

How monetary policy actions feed through to inflation through the currency market is fairly well understood. An expansionary monetary policy depreciates the home currency, thereby increasing the domestic price of imported goods and promoting exports. Over time the lower exchange rate leads to higher output, and, consequently, higher prices. In an emerging market setting, however,

[1] Several papers discuss the dynamic relationship between offshore and onshore RMB exchange rates (e.g. Cheung and Rime, 2014; Owyong *et al.*, 2015). However, no study explores the implications of this dynamic relationship on monetary policy transmission.

this transmission channel may not function properly if the government prevents the exchange rate from fully adjusting.

Moreover, when there an explicit or implicit exchange rate target as in the case of China, the impact of monetary policy on the currency market is at least partially sterilized, thus diminishing the expansionary or contractionary effect of the monetary policy action.

Macro-prudential policies in many emerging economies, including China, feature extensive use of capital controls. When monetary policy changes relative returns between the home currency and foreign currencies, limitations on capital flows restrict changes in the exchange rate and thereby stymy changes in output and price levels.

Barriers to capital mobility may create asset price differentials between the home country and international financial markets.2 As emerging market countries integrate with the global financial market, arbitrage transactions increase as traders seek to avoid capital controls.

This constellation of potential issues is particularly relevant to China due to its coexisting offshore and onshore RMB markets. A shock to the offshore or onshore currency market generates arbitrage opportunities. The resulting arbitrage activity, in turn, causes *both* RMB exchange rates to shift. Such currency fluctuations are hard to anticipate and can push output and aggregate price levels away from central bank targets.

Moving from theory to the real-world Chinese context, we start our analysis by identifying the long-run equilibrium relationship of offshore and onshore RMB exchange rates, economic fundamentals, and capital control measures. Once we have identified the long-run equilibrium for the currency market, we explore China's monetary policy transmission in the context of this long-run equilibrium relationship. We end with an examination of how disequilibrium shocks on the currency market influence inflation expectations and discuss whether the central bank monetary policy toolbox contains instruments to mitigate such impacts.

This study contributes to two strands of the literature.

First, papers on purchasing power parity, or PPP (e.g. Taylor and Taylor, 2004; Hong and Phillips, 2010) typically assume the long-run relationship between exchange rate and PPP fundamental to be linear. Where nonlinearity is considered, it is usually modeled as nonlinear adjustments to a linear long-run relationship. However, as discussed above, emerging market economies often impose capital controls. For a country with capital controls, the impact of changes in the fundamentals on the exchange rate may vary with the degree of capital account openness, and thus, the long-

[2] For example, multiple listings of same stock in home countries and international financial market.

run relationship will be nonlinear. Hong and Phillips (2010) argue that a linear approximation to the nonlinear cointegration relationship is not meaningful due to the lack of constant means of the non-stationary time series that would permit calculation of the linear approximation.

Using the newly developed nonlinear cointegration test of Vogelsang and Wagner (2016), we formally identify a nonlinear long-run equilibrium relationship between the CNY-CNH exchange rate differential, capital controls, and economic fundamentals implied by purchasing power parity (PPP). We further demonstrate that omitting nonlinearity fosters misleading conclusions about China's monetary policy transmission. Since many emerging market economies have capital control measures similar to China's, our results demonstrate the importance of capturing the nonlinearity in the long-run equilibrium of their currency markets. This has obvious implications for the analysis of their monetary policy as well.

Second, we extend the empirical literature on monetary policy transmission in open economies, especially those in emerging market countries. Vector autoregression (VAR) models are widely applied in empirical monetary policy analyses. Eichenbaum and Evans (1995), Kim and Roubini (2000), Faust and Rogers (2003), Scholl and Uhlig (2008), Bjornland (2009), and Kim and Lim (2016) all use linear VAR models to study the responses of exchange rate to monetary policy shocks in open economies. However, these studies focus on short-run dynamics and do not explicitly identify long-run relationships between the exchange rate and PPP fundamental. As mentioned, disturbances to the long-run equilibrium in the currency market can lead to exchange rate fluctuations that affect central bank targets such as an inflation target.

The above-mentioned papers also fail to identify long-run equilibria in the currency market and are silent on the impact of disequilibrium shocks in the currency market. To overcome this, Chong et al. (2012) extend the local projection method of Jorda (2005) to a cointegrated system and show that impulse response analysis of shocks to the long-run equilibrium can be calculated even without imposing any structural restrictions on the VAR system. We extend and apply the method of Chong et al. (2012) to calculate the impulse responses of inflation expectations to a disturbance to the long-run relationship in the currency market.

Chong et al. (2012) focus on a linear cointegrated system, so their approach is best-suited to advanced economies where the relationship between the exchange rate and PPP fundamental are more likely to be linear. As discussed, the presence of capital controls could mean that the long-run equilibrium in the currency market is nonlinear in the Chinese context. For this reason, we extend the approach to allow for a nonlinear long-run equilibrium relationship in the currency market. We believe that this extension well suits monetary policy analysis of emerging market economies with capital controls.

Chong et al. (2012) also use a reduced-form vector error correction model (VECM) for empirical analysis. As they demonstrate, the reduced-form VECM is adequate for identification of impulse responses to disturbances to the long-run equilibrium of a currency market. It is not suited, however, to calculation of impulse responses to monetary policy shocks. This is problematic as the literature suggests that identification of structural policy shocks is important for policy analysis and reduced-form VECM or VAR models usually generate misleading policy implications (e.g. Kuttner, 2001; Cochrane and Piazzesi, 2002; Bernanke and Kuttner, 2005).

To overcome this, we employ a combination of survey data and financial markets data to identify exogenous policy shocks. As suggested by earlier studies (Kuttner, 2001; Cochrane and Piazzesi, 2002; Bernanke and Kuttner, 2005), the use of survey data and financial markets data makes it possible to identify structural policy shocks.

As to policy implications, we find a nonlinear long-run relationship between the CNY-CNH exchange rate difference and the PPP fundamental. The impact of the economic fundamentals on the exchange rate changes with the degree of capital account openness. Specifically, an increase in expected inflation in China relative to the US should depreciate the RMB against the US dollar (USD) if the capital account in mainland China was fully open. As it is not, depreciation of the onshore RMB is less than the depreciation of the offshore RMB, so the increase in the onshore CNY exchange rate is less than that of the offshore CNH exchange rate. Thus, there is a negative relationship between the CNY-CNH difference and the PPP fundamental. This negative correlation is weaker when the capital account is more open as the reaction of CNY to economic fundamentals is closer to the CNH reaction.

Based on the identified long-run relationship between the RMB exchange rates, capital controls and inflation expectations, we can study the implications of the deviations from this long-run equilibrium relationship on inflation expectations. Using a modified version of the local projection methods of Chong et al. (2012), we calculate the impulse responses for inflation expectations to disturbances of the long-run relationship. We find that when the CNY exchange rate is high relative to its long-run equilibrium level, inflation expectations rise. Therefore, disequilibrium in the currency market affects central bank efforts to hit a price stability target.

Unsurprisingly, we also find that expansionary monetary policy raises inflation expectations. We do not find a significant impact of monetary policy on the equilibrium relationship in the currency market, so disequilibrium in the currency market does not completely neuter the influence of Chinese monetary policy over inflation expectations, but the impacts of typical monetary policy surprises on inflation expectations are fairly modest.

When disequilibrium in the currency market causes undesired changes in inflation expectations, it is difficult to offset the impact of such a shock through countervailing monetary policy actions. Capital control measures or currency market interventions might even be needed to restore the currency market equilibrium and stabilize inflation expectations.

The rest of this article is structured as follows. Section 2 presents the institutional setting and policy measures of China's central bank and its counterpart in Hong Kong. Section 3 sets out the methodology and describes the data. Section 4 reviews our empirical results. Section 5 concludes.

2 The offshore RMB market and Chinese policy measures

2.1 The offshore RMB financial market

The pace of RMB internationalization accelerated after the 2008 financial crisis. To facilitate the external use of RMB, China launched a pilot scheme in mid-2009 to ease restrictions on cross-border trade settlements with RMB. The scheme created an RMB pool outside mainland China and helped develop an RMB offshore financial market.

An offshore delivery scheme for offshore RMB-linked products was rolled out in July 2010. The People's Bank of China (PBoC) and the Hong Kong Monetary Authority (HKMA) signed a supplementary memorandum of transactions of RMB products in Hong Kong on July 19, 2010. Hong Kong became the *de facto* prime offshore RMB center and the offshore market took off. The limitation to the Hong Kong market was soon lifted, allowing the creation of several offshore financial centers over the next five years.[3] The daily average turnover of RMB transactions increases from almost nothing to 202 billion between 2007 and April 2016. By April 2016, RMB had become the world's eighth-most actively traded currency (BIS, 2016).

While the RMB is able to flow freely between offshore financial centers outside mainland China, the flow of RMB between mainland China and the offshore market is subject to restrictions. RMB transactions in the onshore Chinese foreign exchange market (CNY market) are regulated by the PBoC. In contrast, the offshore market (CNH) is essentially free. The offshore RMB floats freely

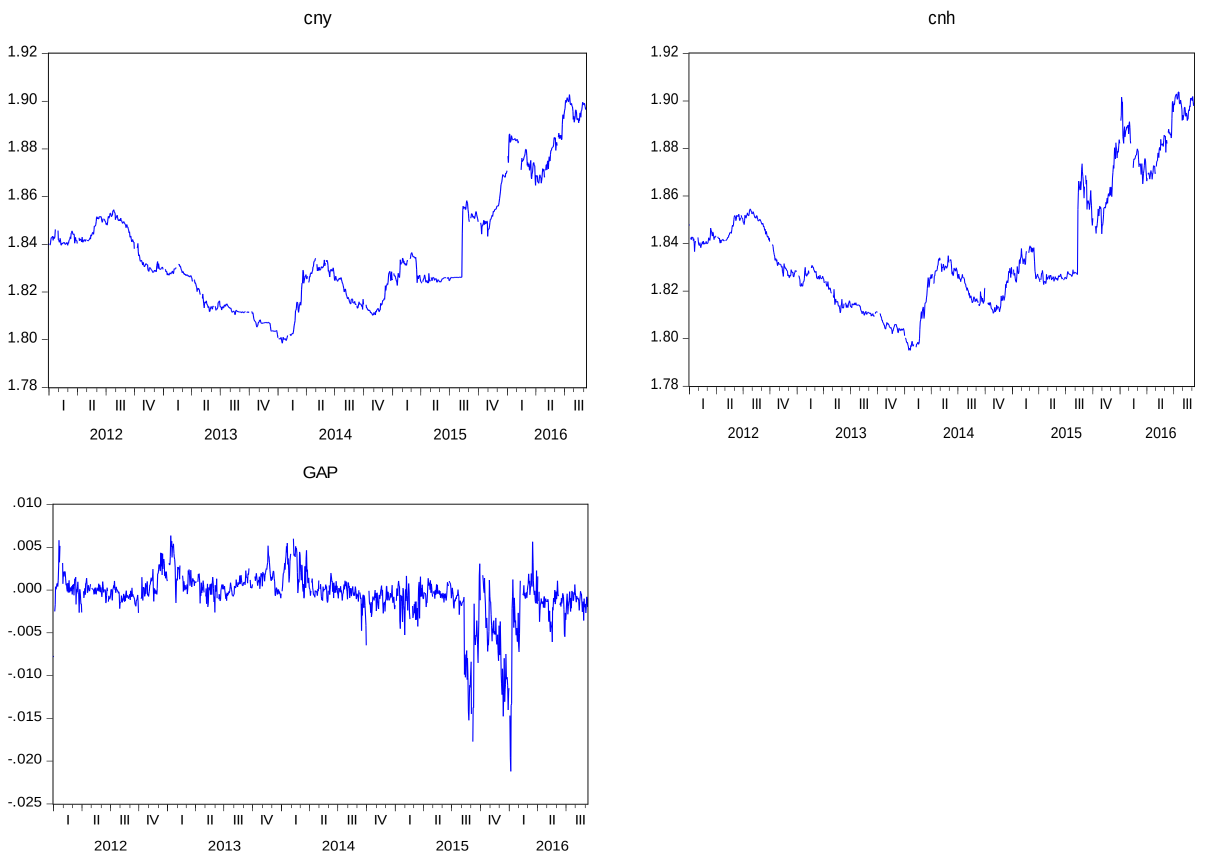
[3] Clearing centers that permit offshore RMB trade have been established in London, Singapore, Taipei, Frankfurt, and other financial hubs.

and is accessible to all offshore participants. Thus, there are two quite distinct markets for the Chinese currency.

Figure 1 presents the time-series graphs of the logarithm of CNY, the logarithm of CNH, and the CNY-CNH difference since December 30, 2011, when the Chinese government began to set quotas for investment in the mainland capital market using offshore RMB. Already we can see that movements in CNH and CNY appear to have nonlinear trend components.

In the first half of the sample, there is a downward trend in both CNY and CNH rates. With strong expectations of RMB appreciation, the CNY exchange rate was only allowed to vary in a narrow band on a daily basis. As a result, RMB appreciated gradually. Interestingly, even if there is no band imposed on the CNH market, we also observe a downward trend that implies arbitraging behaviors across markets closely linked to those two exchange rates.

Figure 1 Time series of exchange rates



Notes: CNY and CNH are log values. Gap is the difference between CNY and CNH.

In the second half of the sample, both CNY and CNH experienced an upward trend. Although CNY and CNH rates have broadly similar trends in their movements, there are persistent deviations between CNY and CNH rates. Here, we observe that the gap between CNY and CNH is positive on average when there is a downward trend, but negative on average when there is an upward trend. The CNY-CNH difference averages 0.00072 (in logarithm) in the first half of the sample and -0.00206 in the second half of the sample. This results from the differences in capital controls and foreign exchange market interventions between the onshore and offshore market.

In the onshore market, capital flows are subject to quotas and the regulated CNY is allowed to fluctuate in a narrow band that is adjusted daily. In the offshore market, capital movements are unrestricted and the CNH exchange rate fluctuates according to supply and demand. Thus, the CNH tends to appreciate more than the CNY in the face of appreciation expectations, which means that the CNY-CNH difference tends to be positive. The CNH exchange rate also increases more than the CNY when there are depreciation expectations, leading to a negative CNY-CNH difference.

2.2 Policy measures in China

The CNY exchange rate is determined by transactions in the China Foreign Exchange Trade System, which in effect is managed by the PBoC. At the start of each trading day, a reference CNY exchange rate is announced and the daily fluctuations of the CNY exchange rate are restricted to a narrow band around this reference rate. To integrate the two markets better, the daily trading band of CNY was widened to $\pm$1% relative to the reference rate in April 2012. It was further widened to $\pm$2% in March 2014.

The CNY reference exchange rate is a weighted average of major dealers' quotes. Dealers had limited flexibility in making quotes until August 11, 2015, when the PBoC reformed its process for setting the reference rate. The daily change of CNY exchange rate still has to lie within the $\pm$2% band, however.

Over the years, the Chinese government has introduced schemes to gradually open up the capital account in a controlled manner. Some have affected the availability and demand of RMB in the offshore market. For example, the Qualified Foreign Institutional Investor (QFII) scheme, launched in December 2002, allowed qualified investors to convert foreign currency to RMB and invest in a number of mainland RMB-denominated financial instruments. The Qualified Domestic Institutional Investor (QDII) program, launched in 2006, allowed approved domestic financial institutions to invest in offshore financial products. Since December 2011, offshore RMB could be used for investments in mainland China through the RMB Qualified Foreign Institutional Investors (RQFII) program. Subject to an aggregate quota, approved non-residents can participate in the onshore equity and bond market using offshore RMB. The RQFII quota was expanded in 2013. Compared to QFII and QDII, RQFII investments do not need to convert between RMB and foreign currencies. However, the investment opportunities granted by the RQFII scheme can affect the incentives for offshore market participants to hold RMB. Therefore, changes in the RQFII quotas can potentially affect the RMB exchange rates.

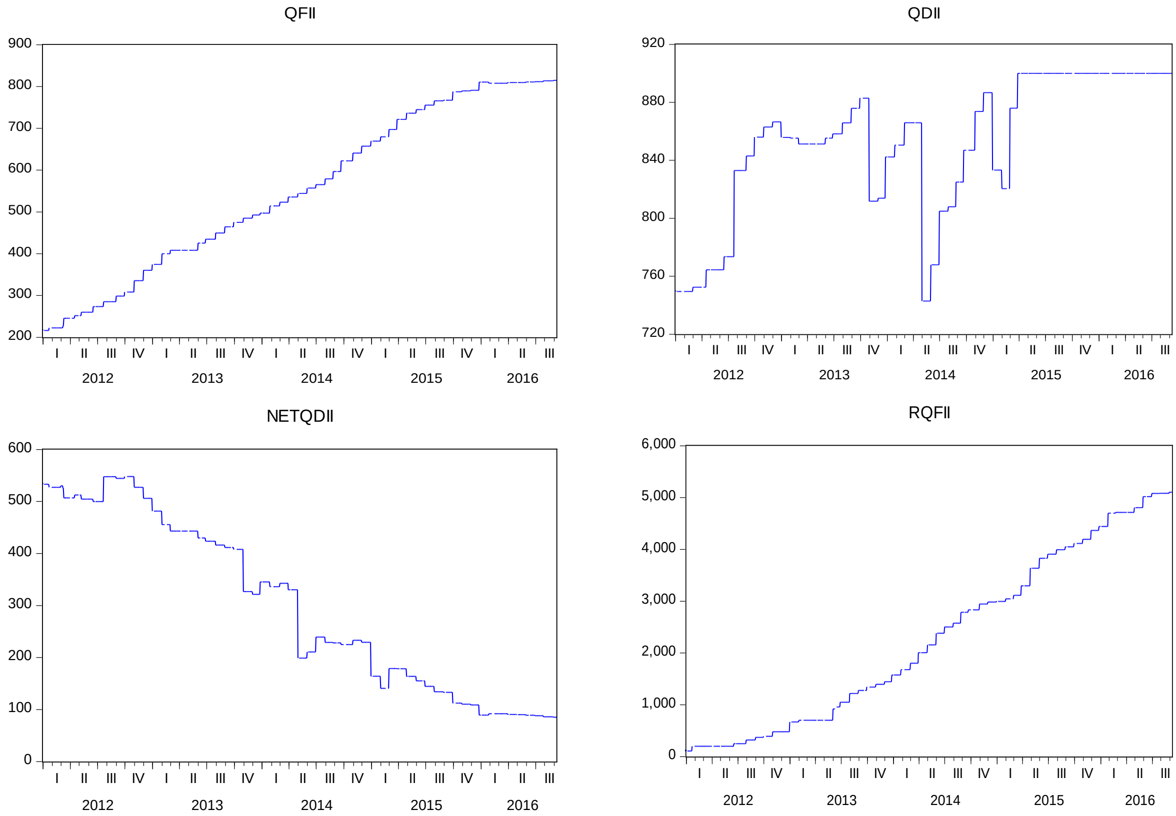
Figure 2 shows the time-series graphs of QFII, QDII, and RQFII. We also report the difference between the QDII and the QFII (NETQDII). This difference reflects the net capital outflow allowed when currency conversions between RMB and foreign currencies are needed. The net capital outflow allowed through the QDII (net of QFII) window has a nonlinear trend. Note the declining trend until the end of 2015, when the level of capital market openness through this window stabilizes. There are still small changes after 2015, but daily changes are relatively insignificant.

The initial declining trend in NETQDII was driven by the increasing trend in the QFII quota. Compared to QFII, the QDII quota fluctuated in a narrow range before 2015 without any apparent trend it. This likely reflects the prudent attitude of the State Administration of Foreign Exchange (SAFE) toward capital outflows. Since March 26, 2015, the QDII quota has remained constant.

Changes in the QFII quota have been quite small since 2016. The smaller changes in the quotas suggest that the Chinese government has become more conservative with respect to capital movements. Part of this relates to the stock market turmoil in 2015 and rising concerns over financial stability. There was also large depreciation pressure on CNH in January 2016.

The slowdown in capital account liberalization was also a reaction to the currency market movements. For RQFII, the growth of the quota accelerated after the second quarter of 2013. The RQFII had 169 institutional participants at the end of September 2016 with had an aggregate approved quota of RMB 511.34 billion.

Figure 2 Time series for the capital control quotas

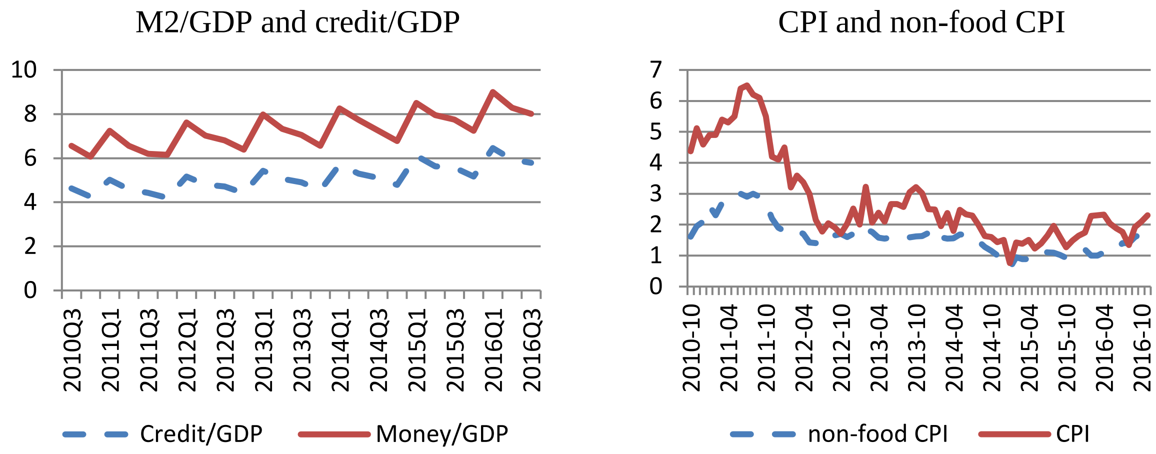


Notes: The units of QFII, QDII, and NETQDII are USD 100 million. The unit of RQFII is RMB 100 million.

These exchange rate and capital account policies may have also influenced domestic economic objectives. Figure 3 depicts the time series of China's consumer price index (CPI) inflation, money supply (M2)-to-GDP ratio, and credit-to-GDP ratio from the third quarter of 2010. Despite obvious seasonality, there is a distinct upward trend in both the money-supply-to-GDP and credit-to-GDP ratios.

Notably, the expansion of money and credit supply relative to the size of the economy does not bring fuel inflation. CPI inflation peaks in July 2011, and thereafter declines from 6.5% to below 3%. It is well recognized that China's CPI inflation rate is heavily affected by food prices. In the same period, the non-food CPI inflation rate fell below 2%. The producer price index (PPI) inflation was negative between March 2010 and August 2016, implying insufficient effective demand for manufacturing goods. Was disequilibrium in the currency market part of reason that China's monetary and credit expansion was so ineffective in fighting deflation?

Figure 3 Time series of China's CPI, money and credit growth



Notes: Data are from China's National Bureau of Statistics. Units for price indices are percentages.

3 Data and methodology

3.1 Data

Our sample covers from December 30, 2011 to March 31, 2016, i.e. a period in which daily data are available. Daily data are important for two reasons. First, the CNH exchange rate data starts from August 26, 2010. The RQFII quota data starts from December 30, 2011. Using monthly or quarterly sample generates small sample biases. Second, with daily data, we can precisely identify surprise macroeconomic news to market participants using the announcement date of the data.

Indeed, the use of monthly data could omit important policy impacts. For example, suppose a structure policy shock has significant positive impacts on the change of the exchange rate on a few days in a month while the impacts are not significant on the other days. A monthly-data analysis might indicate that policy had no impact on the exchange rate. In fact, positive responses of the exchange rate returns raise the level of the exchange rate.

Without subsequent declines in exchange rate returns, the level of the exchange rate pushes persistently higher over the course of the month. Very often, it is this level of the exchange rate that concerns the government. SAFE, for example, pays attention to exchange rate movements as currency depreciation may trigger capital flight. Here, it is the expectation on the prolonged period of higher exchange rate that matters.

We collect daily data of CNY, CNH, QFII, QDII, and RQFII quotas from the Wind database. To construct our policy surprise variables (explained in detail below), we collect survey data on macroeconomic forecasts in China from the Wind database.

3.2 Modeling the long-run equilibrium relationship

As is customary, we assume that the exchange rate between two currencies is determined by the long-run purchasing power parity (see e.g. Taylor and Taylor, 2004). More specifically, if CNY and CNH markets are fully integrated, we have

$$CNY_t = CNH_t = p_t^{CN} - p_t^{US}, \tag{1}$$

where CNY_t is the logarithm of the CNY exchange rate against dollar at time *t*, CNH_t is the logarithm of the CNH exchange rate, p_t^{CN} and p_t^{CN} are respectively the log price level in China and the US.

However, due to capital controls and currency market interventions in mainland China, the CNY and CNH market are not fully integrated. More specifically, capital inflows to the mainland Chinese capital market are limited by the QFII and RQFII quotas. Capital outflows from the mainland Chinese capital market are limited by the QDII quota. In contrast, the capital market in Hong Kong is open to non-residents. Besides the QFII, QDII and RQFII, currency exchange under current account and foreign direct investment (FDI) account are more restricted in the CNY market (Funke *et al*., 2015). As discussed, the government also intervenes more in the CNY market. As a result, market reactions to fundamental economic news are more constraint in the CNY market compared to the CNH market. This creates a gap between the CNY and CNH exchange rate. For brevity, we call $p_t^{CN} - p_t^{US}$ the PPP fundamental. When the PPP fundamental increases, both CNY and CNH exchange rates should increase. However, due to capital controls, CNY increases less than CNH, so the CNY-CNH difference decreases. However, this decrease in the difference is smaller with less constraints on capital movements in the CNY market. Therefore, we have the following nonlinear long-run relationship:

$$\begin{aligned} CNY_t - CNH_t &= a_0 + a_1(p_t^{CN} - p_t^{US}) + a_2 NETQDII_t + a_3 RQFII_t \\ &+ a_4 NETQDII_t * (p_t^{CN} - p_t^{US}) + a_5 RQFII_t * (p_t^{CN} - p_t^{US}) + e_t, \end{aligned} \tag{2}$$

where $NETQDII_t$ is the difference between QDII and QFII quota, which measures the net capital flow allowed when the foreign investors have to convert between RMB and USD, $RQFII_t$ is the RQFII quota, which measures the net capital inflow allowed when the investment currency is in RMB. Because the necessity for currency conversion could affect capital flows, we treat RQFII differently from QFII. As mentioned above, there are also capital control measures under the current account and FDI account. Compared to the NETQDII and RQFII, changes in these measures are less frequent. Their impact is be absorbed in the vector of deterministic terms a_0. Because the PPP fundamental can affect the CNY exchange rate even if capital flows through the capital market are not allowed, a_1 is not necessarily zero. Finally, e_t is the cointegration error.

Ideally, we would also control for QDII and QFII separately. However, QDII, QFII, and RQFII quotas are usually jointly determined by the SAFE's preferences over capital account openness, exchange rate stability, and other macroeconomic concerns. Therefore, these measures are highly collinear. This, controlling the three capital control measures separately on the right-hand side (RHS) causes identification problems.

Indeed, we encounter a matrix singularity problem when all three measures are put on the RHS. To circumvent this problem, we use QDII and QFII to construct the net capital outflow quota, NETQDII. We also regress RQFII on NETQDII and use the residual as the orthogonalized proxy of RQFII. These steps help us better identify the coefficient of NETQDII and RQFII. However, our results from the impulse response analysis are robust if we do not use regression to orthogonalize RQFII.[4]

Chinese inflation data are only reported at a monthly frequency. However, market participants update their inflation expectations more frequently as most have to trade more frequently than monthly. Hence, we use market-implied inflation expectations in our daily-data model. For the US, we use the treasury inflation protected securities (TIPS)-implied 5-year inflation expectations which are directly available from the FRED database. There is no TIPS market in China, of course, so we estimate the market inflation expectations using the term structure model of Rudebusch and Wu (2008). We use their yields-only model for the obvious reason that the macroeconomic information in their macro-finance model is not available at a daily frequency. Yao and Tan (2011) show that

[4] Additional results are available upon request.

inflation expectations derived from this term structure model match survey-based inflation expectations data in China quite well at the monthly frequency. The Chinese term structure data are obtained from the China Central Depository & Clearing Co., Ltd.

Substituting $p_t^{CN} - p_t^{US}$ by the difference between the estimated inflation expectations of China and the US, $INFDIFF_t$, we obtain the following model:

$$
\begin{aligned}
CNY_t &= CNH_t + a_0 + a_1 INFDIFF_t + a_2 NETQDII_t + a_3 RQFII_t \\
&+ a_4 NETQDII_t * INFDIFF_t + a_5 RQFII_t * INFDIFF_t + e_t .
\end{aligned} \tag{3}
$$

The model in equation (3) can also be justified from economic theory. In sticky-price models (Dornbusch, 1976; Frankel, 1979) of exchange rate determination, expected relative inflation rate affects the current-period exchange rate.

Notice also in equation (3) that we restrict the coefficient of CNH in the model to 1. This has two advantages. First, the estimated model has clearer economic interpretation. It tells the impact of a change in the PPP fundamental or capital control measures on the CNY-CNH exchange rate difference. Second, from a theoretical perspective, the right-hand side variables determine both CNY and CNH. Without this restriction, the model suffers serious multicollinearity problems. Of course, the CNH is collinear with all the determinants of RMB exchange rates, so identification of the coefficients is problematic. Even if we can still produce estimated coefficients, the economic interpretation of those coefficients is unclear.

As shown by Hong and Phillips (2010) and Vogelsang and Wagner (2016), the existence of nonlinear terms in the cointegration relationship is difficult to test due to the potential endogeneity of the regressors in the cointegrating equation. Moreover, the error serial correlation requires bias corrections to the standard test statistics to allow for asymptotic chi-squared inference. Vogelsang and Wagner (2016) propose a Ramsey test that has an asymptotic chi-squared distribution based on their Integrated Modified OLS (IM-OLS) estimator (Vogelsang and Wagner, 2014). Therefore, a Wald-type test can be applied. More specifically, consider the cointegrating regression as follows:

$$
\begin{aligned}
y_t &= X_t{}'\beta + u_t , \\
X_t &= X_{t-1} + v_t
\end{aligned} \tag{4}
$$

where the error terms u_t and v_t fulfill a functional central limit theorem, and are potentially correlated with each other. Obviously, when u_t and v_t are correlated, the regressors are endogenous.

Vogelsang and Wagner (2016) show that the OLS estimator of the following equation is consistent and has a zero mean Gaussian mixture limiting distribution.

$$SY_t = SX_t{}'\beta + SM_t{}'\gamma + X_t{}'\alpha + w_t, \tag{5}$$

where $SY_t = \sum_{j=1}^{t} y_j$, $SX_t = \sum_{j=1}^{t} X_j$, SM_t is similarly defined as a partial sum of the cross products of elements in X_t . w_t is the error term.

After estimating equation (5), chi-squared tests can be applied to test the significance of β and γ. Obviously, when the null hypothesis of $\gamma = 0$ is rejected, we can conclude that the long-run equilibrium relationship is nonlinear. We apply this IM-OLS test to our model (3) in the empirical analysis.

3.3 Impulse response analysis

Chong *et al.* (2012) suggest that if a cointegration relationship is found in the data, we can calculate the impulse responses of the economic system with the following two local projections.

$$\begin{aligned} e_{t+h} &= A_1^h e_t + \Phi_1^h \Delta Y_t + \ldots + \Phi_p^h \Delta Y_{t-p+1} + \eta_{t+h}, \\ \Delta Y_{t+h} &= B_1^h e_t + \Psi_1^h \Delta Y_t + \ldots + \Psi_p^h \Delta Y_{t-p+1} + \varepsilon_{t+h}, \end{aligned} \tag{6}$$

where h=1,…,H is the forecast horizon. Specifically, the first equation in (6) describes linear projections of the h-step-ahead equilibrium errors on the current equilibrium error and the current and past values of the endogenous variables. The second equation in (6) describes linear projections of the h-step-ahead values of the endogenous variables on the same set of variables. η_{t+h} and ε_{t+h} are error terms.

Jorda (2005) introduces the local projection method as an alternative way to calculate impulse response functions using VAR. This method consistently estimates the impulse responses of a system of stationary variables. Its advantage over traditional VAR is that it requires no specific model specification and thus avoids potential specification errors.

The two local projections in (6) are extensions of the Jorda (2005) approach to non-stationary dynamic systems. One nice property of the local projection system in (6) is that the h-step impulse responses of endogenous variables to a disturbance to the long-run equilibrium relationship can be simply calculated as $B_1^h + \Psi_1^h \beta$, where β is the vector of cointegration coefficients. The impulse responses to the shocks in ε_{t+1} are $B_1^h \beta' + \Psi_1^h$. To control for the nonlinearity, the interaction term $NETQDII_t * INFDIFF$ is added to the right-hand side of the local projection systems in (6).

In the typical exchange rate model presented in Chong *et al.* (2012), the interest rate difference between two countries is added to ΔY_t to capture the uncovered interest rate parity (UIP) effect. In this context, impulse response functions (IRFs) to interest rates may be interpreted as the impact of interest rate policy. However, the error terms in the reduced-form system (6) are not structural. In other words, they might be a combination of deeper structural economic shocks. Therefore, the economic interpretation of the IRFs is difficult.

Moreover, Cochrane and Piazzesi (2002) point out that market participants may have anticipated current changes in interest rates. In such case, current exchange rates already contain information on anticipated interest rate changes and no further responses to interest rate changes should be seen in exchange rates. To overcome this, we substitute the usual interest rates in the exchange rate models with two surprise monetary policy measures.

The US monetary policy shock is estimated as the difference between the announced changes in the federal funds rate and anticipated changes implied by the futures market for federal funds. Kuttner (2001) as well as Bernanke and Kuttner (2005) provide a detailed explanation of how this variable is constructed.

As there is no futures market for Chinese interbank funds, we use survey data to construct our surprise monetary policy indicator of China. It is widely acknowledged that quantity-based policies have traditionally been used much more than interest rate policy in China (see e.g. He *et al*., 2013; Cheung *et al*., 2016; He *et al*., 2016), and that money supply and credit supply are closely monitored and regulated by the central bank. The Wind database surveys the major financial institutions in China on key macroeconomic variables including M2 growth and the flow of credit supply on a monthly basis. Hence, we can construct the money supply shock and credit supply shock by the difference between the realized data and the median survey of the forecasts. Since the PBoC has better control over credit supply than the money aggregate, we use the credit supply shock in our benchmark model. However, our results are robust if we use the M2 shock as the monetary policy indicator.

In addition to the two monetary policy variables, we also control for two surprise indicators of real activities. Scotti (2016) demonstrates that an aggregate index of surprise news on real activities significantly affects asset prices. We use his US surprise index, *Ussurp*, as a control variable in our model. There is no aggregate index of surprise news on real activities in China. We use the difference between realized industry production and survey median forecast of industry production, *Industry_cn*, instead. Data on *Ussurp* is from Scotti (2016). The survey median forecast of China's industrial production is taken from the Wind database.

In summary, our extended system of local projections is as follow:

$$e_{t+h} = A_1^h e_t + \Phi_1^h \Delta Y_t^{ex} + \ldots + \Phi_p^h \Delta Y_{t-p+1}^{ex} + \eta_{t+h}, \tag{7}$$

$$\Delta Y_{t+h} = B_1^h e_t + \Psi_1^h \Delta Y_t^{ex} + \ldots + \Psi_p^h \Delta Y_{t-p+1}^{ex} + \varepsilon_{t+h},$$

$$\Delta Y_{t+h} = \left(\Delta CNY_{t+h},\ \Delta CNH_{t+h},\ \Delta INFDIFF_{t+h},\ \Delta NETQDII_{t+h},\ \Delta RQFII_{t+h}\right)',$$

$$\Delta Y_t^{ex} = \left(\Delta Y_t',\ \Delta INFDIFF_t * NETQDII_t, Credit\_cn, Interest\_us, Industry\_cn, Ussurp\right)'.$$

Here, we use *Credit_cn* and *Interest_us* to denote the surprise credit supply in China and surprise federal funds rate (FFR) change in the US. Since the surprise variables are exogenous by construction, we do not need to put them on the left-hand side of the equations.

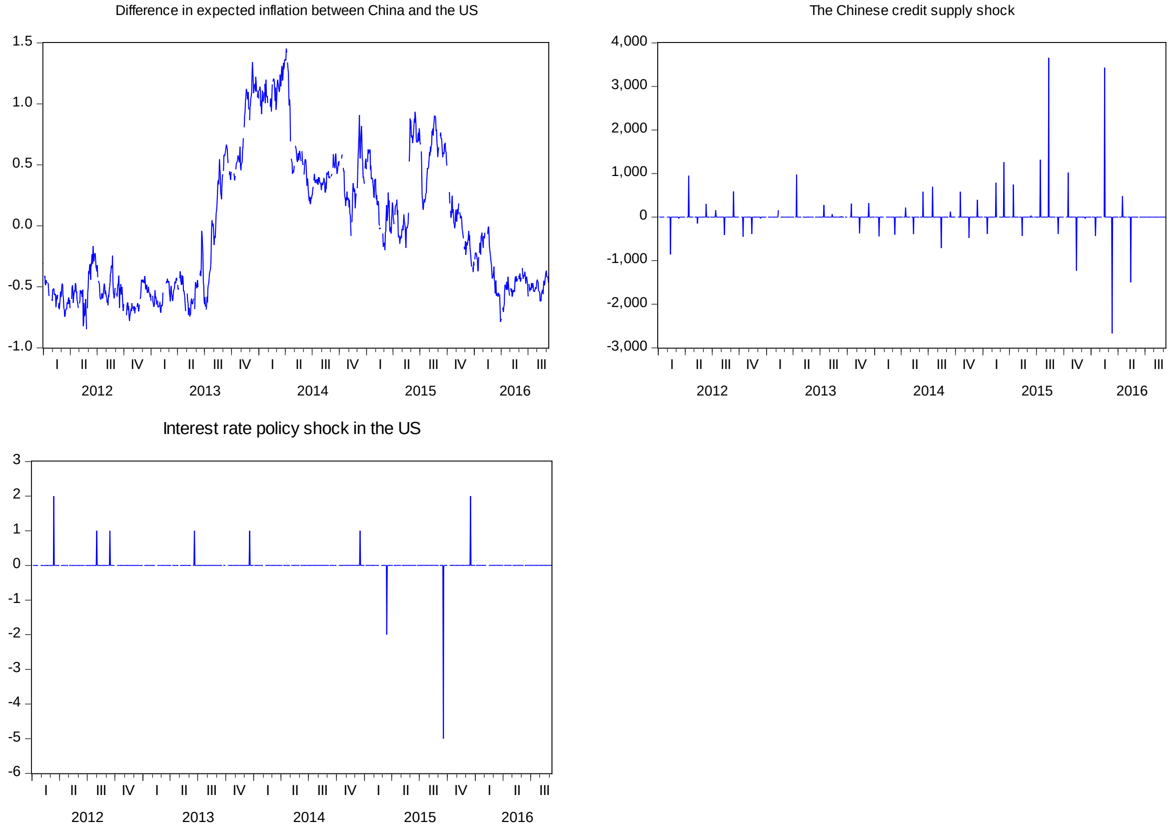
4 Empirical findings

4.1 The expected inflation difference and surprise policy variables

The upper-left panel of Figure 4 plots the time series of $INFDIFF_t$. The expected inflation difference between China and the US in the first half of the sample was, on average, negative (-0.09 percent). This implies that the exchange rate should decrease. However, the average expected inflation difference turned positive (0.10 percent) in the second half of the sample. This relatively high inflation expectation in China should lead to a higher exchange rate. However, due to the exchange rate and capital account regulations, the adjustment is a gradual process. Therefore, we observe downward trends in in the CNY and CNH exchange rates in the first half of the sample and upward trends in the second half of the sample. This reasoning is consistent with the time series plots of the CNY and CNH exchange rates in Figure 2.

Figure 4 also shows the time series plots of the Chinese credit supply shock and US interest rate policy shock.

Figure 4 Expected inflation difference and policy shocks



Notes: The unit of INFDIFF is percentage. Policy shocks data are based on authors' calculations. The unit of the Chinese credit supply shock is RMB 100 million. The unit of the US interest rate policy shock is basis point.

4.2 Long-run equilibrium relationship

Before performing the cointegration test, it is necessary to test whether the variables in model (3) are truly I(1) variables. Table 1 summarizes the unit root test results. The unit root hypothesis is clearly not rejected for all the level variables in model (3). On the other hand, the first differences are shown to be I(0) variables. Therefore, it is suitable to perform a cointegration test for model (3). We remove quadratic deterministic trends from CNY, CNH, NETQDII, and RQFII before our cointegration analysis.

Table 1 Unit root test results

	CNY	CNH	NETQFII	RQFII	INFDIFF
Level	–0.7669	–1.5545	–2.6308	–2.8331	–1.4497
First difference	–29.23***	–30.61***	–24.14***	–31.19***	–30.46***
Trend in test	Yes	Yes	Yes	Yes	No

Notes: The test is the augmented Dicky-Fuller test. The null hypothesis assumes a unit root. The lag length of the test is selected by the Schwarz information criterion. We denote statistical significance at the 1%, 5%, 10% percent by ***, **, *, respectively. The row "Level" corresponds to the test t-statistics for the level of the variables. The row "First difference" corresponds to the test t-statistics for the first difference of the variables. The row "Trend in test" tells whether the test includes a deterministic trend. All tests include an intercept.

Using the nonlinear cointegration technique of Vogelsang and Wagner (2016), we identify the following long-run relationship:[5]

$$CNY_t = CNH_t - \underbrace{0.0017}_{(p=\ 0.0104)} INFDIFF_t - \underbrace{0.0588}_{(p=0.1054)} NETQDII_t - \underbrace{0.0963}_{(p=0.8270)} RQFII_t + \underbrace{0.3392}_{(p=0.0030)} NETQDII_t * INFDIFF_t. \quad (8)$$

The p-values in the parentheses under the estimated coefficients are those of the tests of the zero-coefficient null hypothesis. The interaction term between RQFII and INFDIFF is not significant when included. Moreover, *RQFII*INFDIFF* is not only correlated to the level variables, *RQFII* and *INFDIFF*, but also correlated to the other interaction term. Therefore, the addition of this variable also makes the multi-collinearity problem more serious. As a result, all individual coefficients appear to be insignificant when two interaction terms are added. Therefore, we report the estimated model without *RQFII*INFDIFF*.

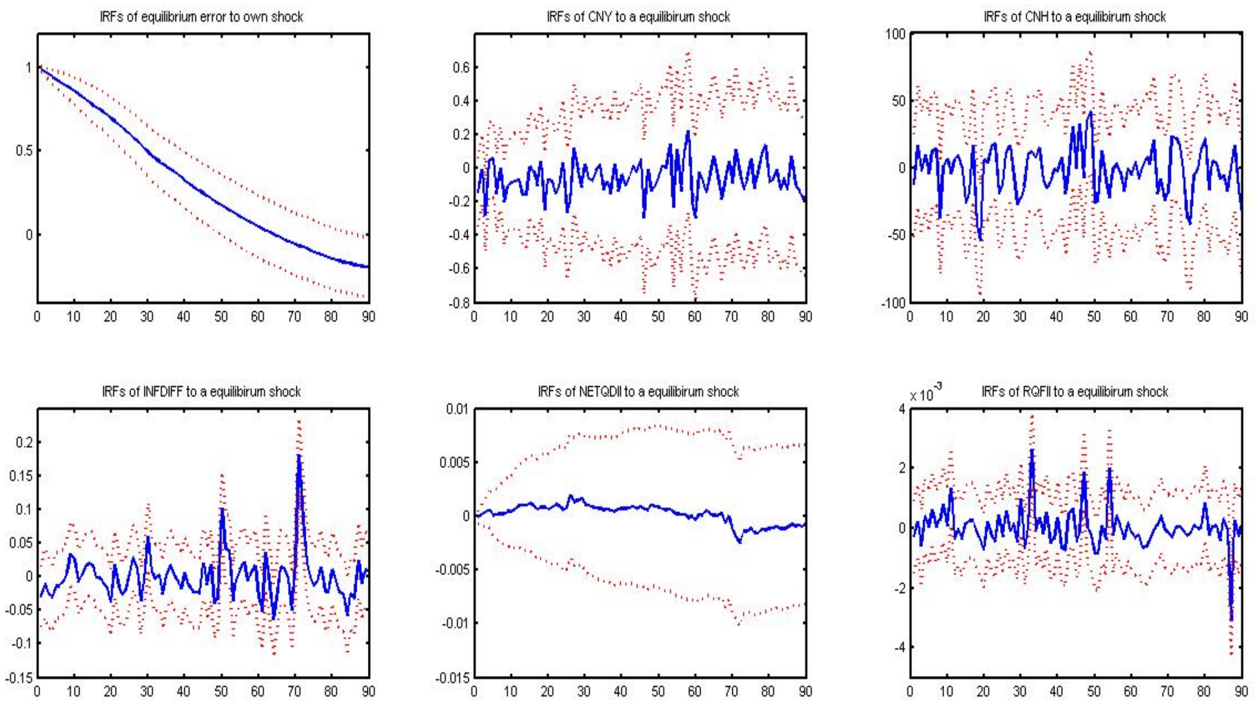
As expected, an increase in the expected inflation difference raises RMB exchange rates, but, because of capital controls the CNY less. Thus, INFDIFF has a negative sign.

[5] To make the coefficients of the quotas visible within four digits, we have changed the units of the NETQDII and RQFII quotas to USD 10,000 and RMB 10,000, respectively.

4.3 The impact of a disturbance to the long-run equilibrium relationship

Figures 5 and 6 present the impulse response functions, or IRFs, of the error correction term and first differences of CNY, CNH, INFDIFF, NETQDII, and RQFII to a one-unit shock to the equilibrium relationship. Figure 5 presents IRFs up to 90 days. To facilitate our reading of the more immediate responses, we separately report the IRFs up to 30 days in Figure 6.

Figure 5 Impulse responses to disequilibrium error (90 days)

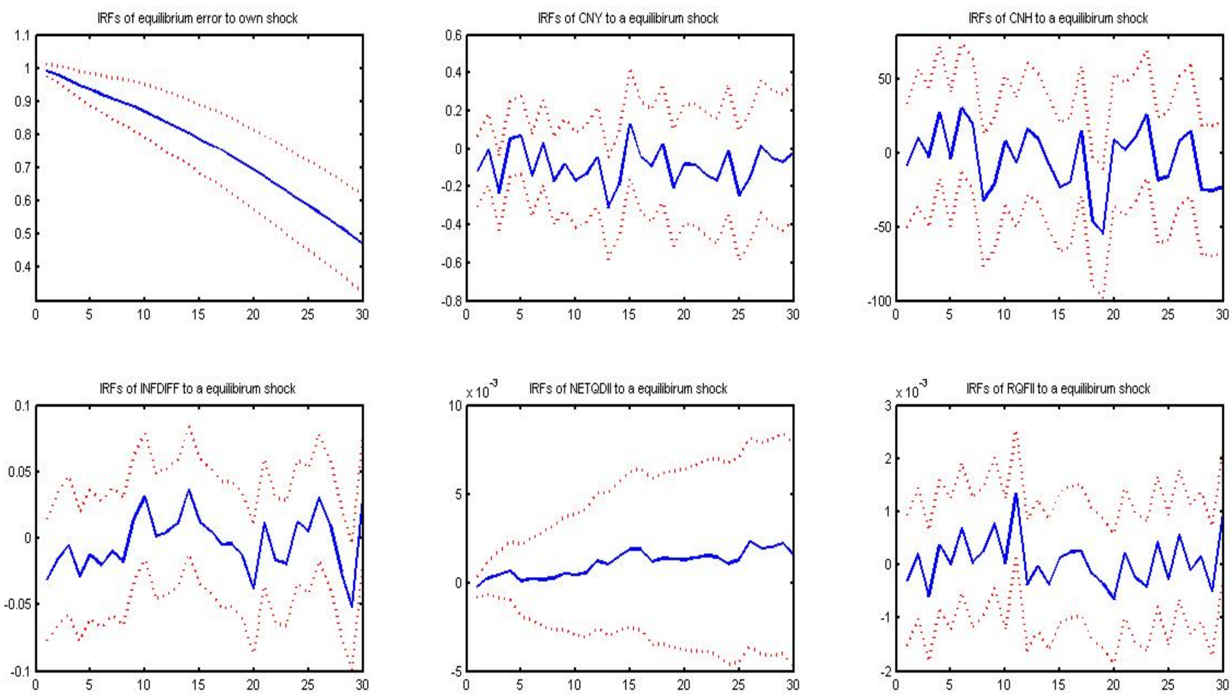


Notes: ECT denotes the disequilibrium error term, CNY, CNH, INFDIFF, NETQDII, and RQFII are first differences. The variable on the horizontal axis is the number of days after the shock. The variables on the vertical axis are the responses. The dashed lines are the 95% intervals.

The first observation is that a temporary shock to the long-run relationship has a very persistent impact. The IRF of the error correction term does not converge within 90 days. This is consistent with the literature (Taylor and Taylor, 2004; Chong *et al*., 2012).

Second, disequilibrium on the currency market seems to have little impact on the inflation expectations in the first month following a disequilibrium shock. The impulse responses are not significantly different from zero on most days in that month. However, the shock significantly raises inflation expectations within a quarter. More specifically, our indicator of expected inflation difference rises by 0.1 percent on day 50 and 0.18 percent on day 71 after a 1-percent over-depreciation of the CNY. Note that there are no subsequent significant drops in the *first difference* of INFDIFF. Therefore, the *level* of inflation expectations in China has been persistently higher than the before-shock periods after those two days.

Figure 6 Impulse responses to the disequilibrium error (30 days)



Notes: ECT denotes the disequilibrium error term, CNY, CNH, INFDIFF, NETQDII, and RQFII are first differences. The variable on the horizontal axis is the number of days after the shock. The variables on the vertical axis are the responses. The dashed lines are the 95% intervals.

Movements in expected inflation are helpful for the restoration of the long-run equilibrium. The disequilibrium shock makes the CNY exchange rate overly high relative to the level implied by the fundamentals. Rising inflation expectations close the gap.

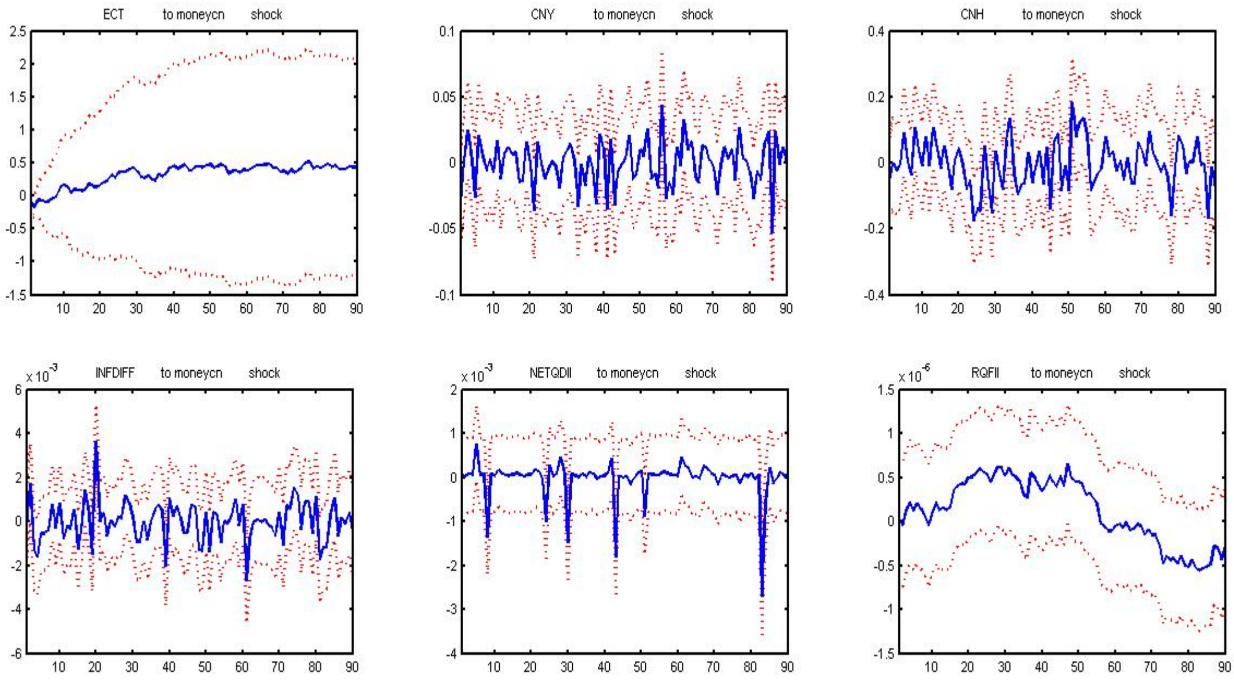
In contrast, there are no notable significant responses of the exchange rates to the disequilibrium shock. Note that the IRFs of CNH have large magnitudes, but the intervals are also very wide and almost always cover zero except on day 18 and 19. On those two days, the upper bounds of the 95% confidence interval are negative, which implies that CNH appreciates on those two days. These responses push in the "wrong" direction; the shock makes the CNY exchange rate excessively high relative to the CNH, so the CNH exchange rate must rise as well to restore equilibrium. Therefore, the equilibrium is obviously *not* restored by the movements in the CNH.

The IRFs of CNY are also mostly insignificant except on day 3 when the upper bound of the 95% confidence interval is negative. This implies that the CNY appreciates on that day. Because the equilibrium error over-depreciates, the CNY relative to the level implied by the long-run equilibrium relationship, CNY appreciation corrects the error. However, the magnitude of the response is small (range of -0.4947% to -0.0690%).

4.4 Impact of a surprise credit expansion

Figures 7 and 8 summarize the IRFs of equilibrium error and endogenous variables to a one-unit increase in the credit supply in China up to 90 and 30 days, respectively.

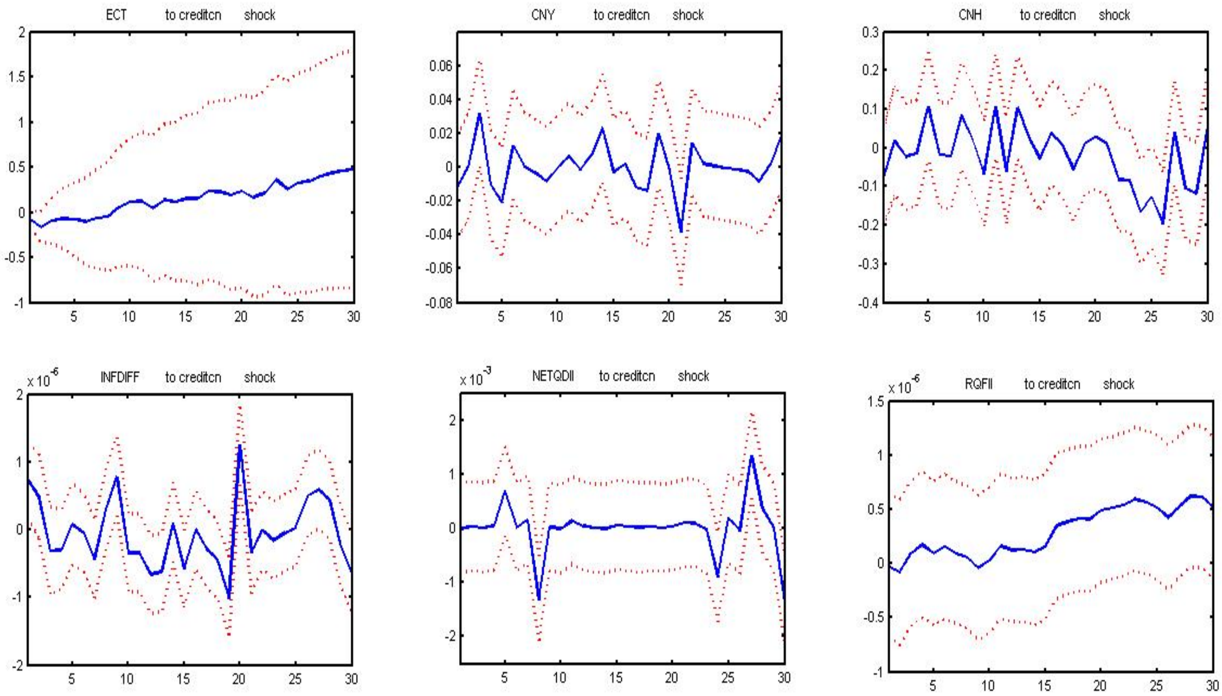
Figure 7 Impulse responses to a one-unit shock of credit supply in China (90 days)



Notes: ECT denotes the disequilibrium error term, CNY, CNH, INFDIFF, NETQDII, and RQFII are first differences. The variable on the horizontal axis is the number of days after the shock. The variables on the vertical axis are the responses. The dashed lines are the 95% intervals.

Obviously, the expansionary credit shock has no significant impact on the equilibrium error. Hence, there is no evidence that credit policies in China contribute to currency market disequilibrium. Moreover, the credit shock effectively raises inflation expectations. The impact responses are largest on day 20 and 81. On day 20 and 81 after a RMB 1 trillion increase in the credit supply, inflation expectations in China (relative to the US) are raised by 0.0182 percent and 0.0189 percent, respectively. The magnitudes of these impacts are small, but persistent. Note that the IRFs are in first differences. Without significant negative IRFs after those two days, the level of inflation expectations is persistently higher.

Figure 8 Impulse responses to a one-unit shock of credit supply in China (30 days)



Notes: ECT denotes the disequilibrium error term, CNY, CNH, INFDIFF, NETQDII and RQFII are first differences. The variable on the horizontal axis is the number of days after the shock. The variables on the vertical axis are the responses. The dashed lines are the 95% intervals.

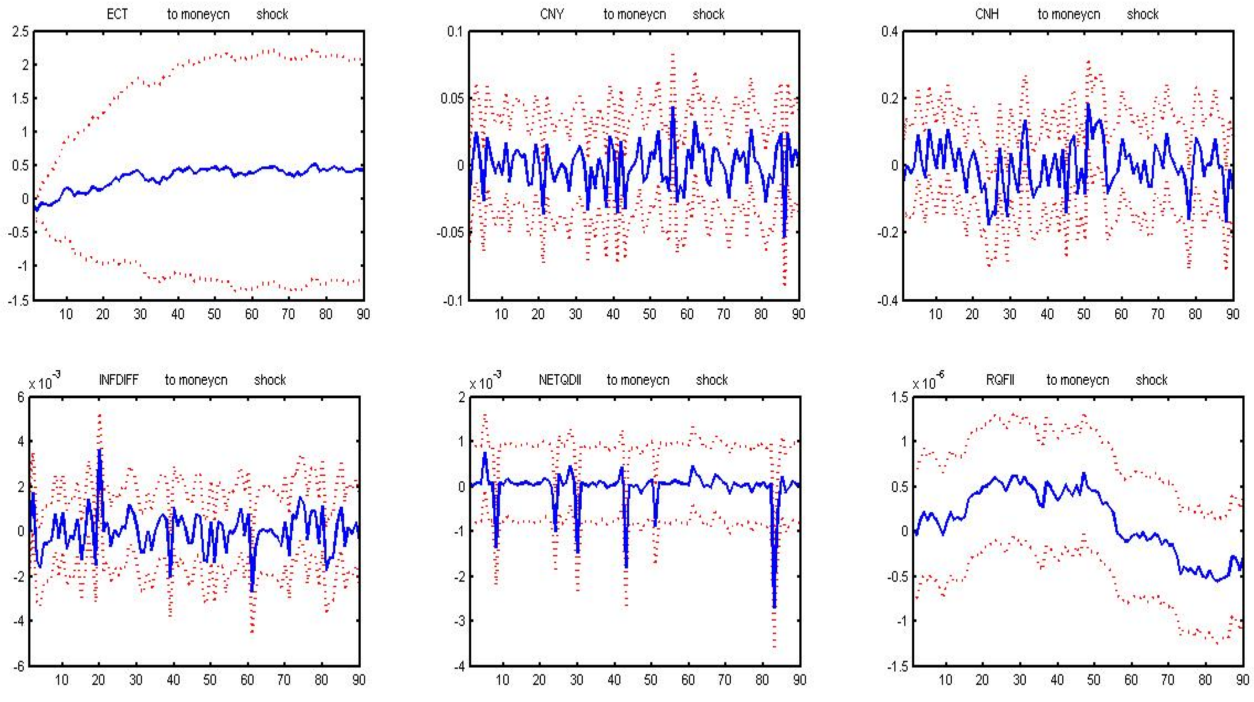
These findings suggest that disequilibrium in the currency market does not have a significant impact on the transmission of credit policy shocks to inflation expectations. They do not mean that disequilibrium in the currency market does not affect the central bank’s ability to maintain price stability. As we found in the previous subsection, a one-percentage-point over-depreciation of CNY can create daily changes in inflation expectations to a scale about ten times larger than an RMB 1 trillion credit surprise. Although monthly credit increase in China can be larger than RMB 1 trillion, creating a surprise credit supply is far more difficult because the market can anticipate a large part of the credit supply. The largest Chinese credit supply shock in our sample is RMB 365.68 billion (Figure 4). This means that a moderate shock to the equilibrium of the currency market can easily negate the impact of a large-scale credit policy on the inflation expectations.

This finding helps us understand the phenomenon shown in Figure 3. Despite the persistent increase in money and credit supply, China's inflation rate remains low. Currency market disequilibrium seems to have defanged expansionary monetary and credit policy.

4.5 Robustness of the impulse responses functions

Previously, we used credit supply as the monetary policy variable for China. In this subsection, we show that our qualitative results on monetary policy transmission are unchanged if shocks to aggregate money supply growth rate are used. Figures 9 reports the IRFs of the equilibrium error and endogenous variables to a one-unit increase in the M2 growth rate in China up to 90 days. (To save space, we do not separately report the IRFs of the first 30 days for the robustness tests).

Figure 9 Impulse responses to a one-unit shock of money supply in China (90 days)



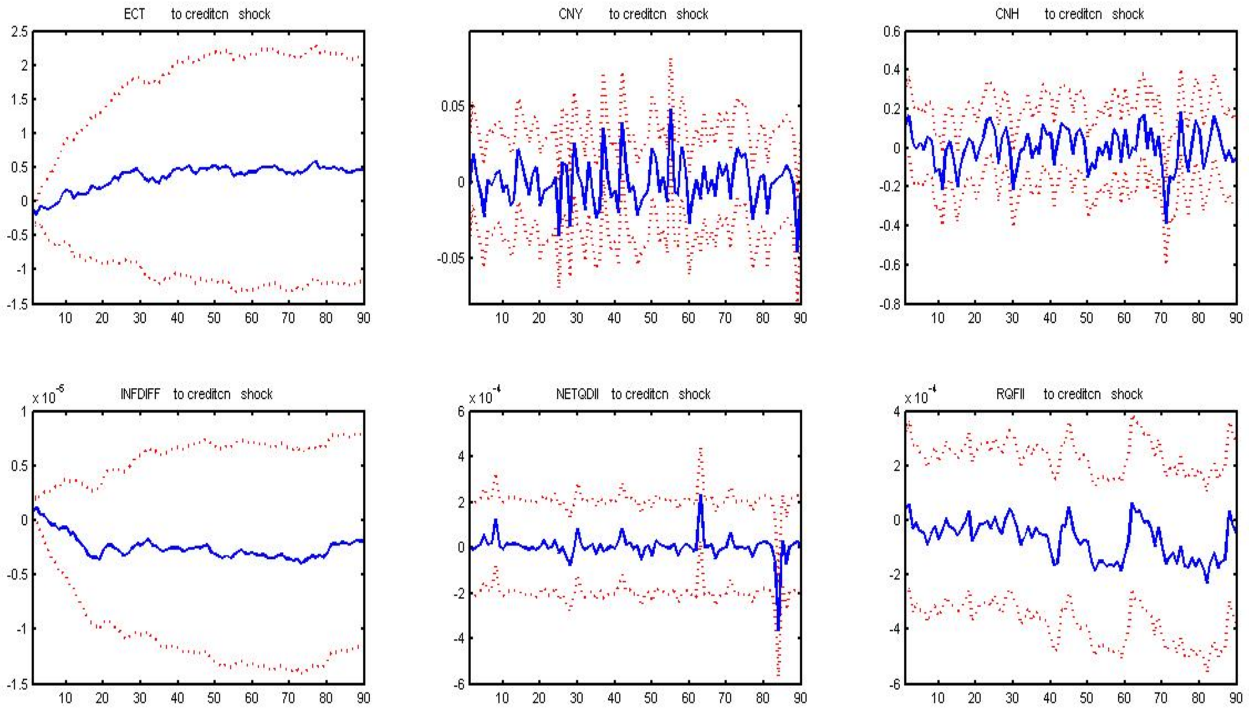
Notes: ECT denotes the disequilibrium error term. CNY, CNH, INFDIFF, NETQDII, and RQFII are first differences. The variable on the horizontal axis is the number of days after the shock. The variables on the vertical axis are the responses. The dashed lines are the 95% intervals.

A surprise increase in the money growth rate leads to a significant increase in inflation expectations on day 20. By contrast, no significant IRFs of the exchange rates are found. Therefore, monetary policy is effective in shaping inflation expectations and does not bring significant distortions to the currency market. However, as what we found earlier, the responses to inflation expectations are rather small. The largest response of inflation expectations to a one-percent money growth shock is only 0.006 percent.

4.6 The importance of nonlinearity

As we set forth in the introduction, most empirical studies on the long-run relationship between the exchange rate and PPP fundamental assume a linear relationship. For a country with capital controls like China, the potential nonlinear relationship could affect the qualitative results of policy analysis and lead to faulty inferences and bad policy decisions. Figure 10 reports the IRFs of the equilibrium error and endogenous variables to a one-unit increase in the credit supply in China up to 90 days in a linear model. These IRFs suggest that a credit supply shock has no impact on the inflation expectations in China, a clearly false finding in light of the above discussion.

Figure 10 Impulse responses to a one-unit shock of credit supply in China (linear model



Notes: ECT denotes the disequilibrium error term. CNY, CNH, INFDIFF, NETQDII, and RQFII are first differences. The variable on the horizontal axis is the number of days after the shock. The variables on the vertical axis are the responses. The dashed lines are the 95% intervals.

5 Conclusions

With rapid development of RMB as an international currency, China has sought since 2010 to foster offshore RMB markets for financial transactions among non-residents. Even as the offshore CNH market rapidly developed, a persistent difference between CNY and CNH rates has generated massive speculation and complicated the aggregate environment in which the PBoC applies its policy instruments.

We have shown here that there are nonlinear long-run relationships between the onshore and offshore RMB exchange rates and expected inflation. This nonlinearity is caused by China's capital control policies and currency market regulations. Policymakers should be aware that traditional analyses fail to capture this nonlinearity and, if the problem is ignored, could lead to inappropriate conclusions about the transmission of monetary policy shocks to inflation expectations.

Based on the identified long-run relationship, we calculate the impulse responses of inflation expectations to a disturbance to the long-run relationship. It shows that disequilibrium in the currency market can affect the price stability target of the central bank. More specifically, although monetary policy shocks in China can still effectively change inflation expectations, the magnitudes of these effects are quite small. Discretionary monetary policy might fail to fight deflation and recession when the currency market is in disequilibrium, however. This is because the impact of a moderate-size equilibrium error in the currency market on inflation expectations is much larger than the impact of a typical surprise credit supply or money shock. Therefore, measures have to be taken to maintain currency market equilibrium if the central bank wants its policy instrument to manage inflation expectations effectively.

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