Tolerance of Flexibility: Foreign Exchange Intervention and Managed Floating Redux *

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Abstract

In recent decades, there has been a rising share of countries with limited exchange rate flexibility (Ilzetzki et al., 2019), and foreign exchange (FX) intervention is commonly used among emerging market economies. Yet, the positive and normative implications of central banks' FX intervention and managed floating regime remain largely unexplored. Focusing on the case of China, we provide new empirical patterns of China's exchange rate policy after the global financial crisis. We find strong evidence that the central bank's FX intervention policy is nonlinear: it intervenes in heavily when the RMB exchange rate deviates from its long run trend by a large margin and otherwise it keeps inactive. Further, the central bank's purchasing or selling U.S dollars in FX markets has different implications for the monetary policy. To assess the policy effects of managed floating, we embed the Aoki et al. (2018) model of open economy with an occasional binding constraint on the exchange rate. We find that managed floating would lead to higher volatility of output, inflation and capital price in the absent of capital controls. However, with macroprudential policies, it could achieve greater economic and financial stability in the medium/long run, compared to pure float.

Keywords: Managed float, Nonlinear FX intervention, Occasional binding constraints, Capital controls, Monetary policy, China's currency, RMB

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1 Introduction

Exchange rate regimes and capital controls are the central themes in international finance. The traditional Mundell's trilemma states that it is not feasible to have at the same time a fixed exchange rate, full capital mobility, and monetary policy independence.[1] In reality, a majority of countries neither freely float their currencies nor firmly peg to another currency, especially for emerging market economies (EMEs). In response to financial crises and their devastating consequences, foreign exchange (FX) interventions through changes of reserves, and capital flow management (CFM), have became part of the standard crisis prevention policy toolkit for EMEs.[2] Ilzetzki et al. (2019) document a rising share of countries with limited exchange rate flexibility, together with a record accumulation of reserves after 2002, which are closely related to many countries' desires to stabilize exchange rates.

Managed floating is known as one of the most popular intermediate exchange rate regimes, where the central banks intervene in the FX market and curb excessive exchange rate fluctuations. It is now the largest category among exchange rate regimes according to Ghosh et al. (2015) and Ilzetzki et al. (2019). How do central banks intervene in the FX market under the managed floating regime, and what are the macroeconomic and financial consequences of FX intervention and capital flows management? The importance of this question has attracted a number of economists over the years, such as Krugman (1991), Calvo and Reinhart (2002), Klein and Shambaugh (2015) and Frankel (2019),[3] yet there has been little in the way of systematic empirical investigation and formal modelling in a structural open macroeconomic framework. The goal of this paper is to fill the gap by providing an integrated analysis on the positive and normative aspects of managed floating.

While many emerging economies are managed floaters, this paper focuses on the case of China. These days, interest focuses on China's exchange rate, given that China's currency, the Renminbi or RMB, is becoming ever more important in world trade and payments. Meanwhile, China has abandoned the hard peg to the U.S. dollar (USD) since 2005 and claim that they adopt the *managed floating* exchange rate regime. China's central bank,

[1] See the recent work by Farhi and Werning (2012), Schmitt-Grohé and Uribe (2012) and Klein and Shambaugh (2015).

[2] After the global financial crisis, the traditionally conservative IMF started to rethink its policy paradigm. For exchange rate policy, Ghosh et al. (2015) argue that "managed floats," a subclass within intermediate regimes, behave much more like pure floats, with significantly lower risks and fewer crises. For capital control policy, IMF (2012) advocated a comprehensive, flexible, and balanced approach for the management of capital flows.

[3] Many countries, especially EMEs, are reluctant to let the exchange rate float freely, probably due to the "fear of floating" (Calvo and Reinhart, 2002) or other concerns on macroeconomic and financial stability/uncertainty (Benigno et al., 2016; Lei et al., 2018).

People's Bank of China (PBC), frequently intervenes in the RMB FX markets, primarily through the purchases and sales of reserves, without a pre-announced rule.[4] How exactly PBC manages the RMB exchange rate can have far-reaching effects on the global financial market and matters for the transmission of global financial shocks (Obstfeld et al., 2018).

We first document some novel empirical patterns regarding China's RMB exchange rate policy. Evidence from structural break tests and Markov regime switching models indicate that the PBC's FX intervention does not follow a simple linear rule. Instead, it shows that PBC intervenes in the exchange rate in certain periods but keeps almost inactive in other periods. We identify the strong and weak FX intervention regimes and find that the states link to how much the RMB/USD exchange rate deviates from its long run trend. We observe the central bank's *tolerance of flexibility*: PBC will strongly intervene the FX market to prevent the RMB appreciation/depreciation if the exchange rate deviates far enough from the long run trend. Otherwise, PBC's FX intervention is so weak that it is insignificantly different from zero. The results are robust when we consider the exchange rate of a currency basket, rather than the U.S. dollar rate. Regarding the short run deviation, the central bank's reaction coefficients are not statistically significant. Furthermore, the central bank reacts asymmetrically to exchange rate appreciation and depreciation, with a higher tolerance on flexibility when the exchange rate experiences a large depreciation.

Motivated by these empirical patterns, the paper constructs a structural macroeconomic model to study the positive and normative implications of a nonlinear FX intervention. Specifically, following the lead of Schmitt-Grohé and Uribe (2003) and Chang et al. (2015), we build a simple open economy model with an occasional binding constraint on exchange rate fluctuations. The model is then solved using the piecewise linear algorithm proposed by Guerrieri and Iacoviello (2015).[5] The goal is to compare the exchange rate policy in a structural macroeconomic model with and without FX intervention, especially managed floating in the presence of capital controls. We find that intervening in the exchange rate brings larger volatilities to most of the variables, and that moving from managed floating to fully floating increases welfare. Furthermore, when capital account restrictions are removed, the exchange rate deviation constraint binds longer in response to the same shock. In other words, managed floating and capital controls are complements in terms of stabilizing

[4]See Clark (2017). Instead of using FX intervention to directly adjust the demand and supply in the FX market, PBC has access to a variety of other tools, e.g.,central parity and trading band, the associated bands, capital flows management (CFMs), and-after May 2017-the use of the "counter-cyclical" factor. See Jermann et al. (2017), Lei et al. (2018) and Das (2019) for details.

[5]Guerrieri and Iacoviello (2015) provide the toolkit called *OccBin* to solve dynamic models with occasionally binding constraints. Their algorithm has been used in many macroeconomic models to study the zero lower bound of interest rate (Gust et al., 2017), collateral constraints (Guerrieri and Iacoviello, 2017).

exchange rate fluctuations. We take a further step to study the full model with financial frictions and currency mistmatch, similar to Aoki et al. (2018). We find that managed floating would lead to higher volatility of output, inflation and capital price in the absent of capital controls. However, with macroprudential policies, it could achieve greater economic and financial stability in the medium/long run, compared to pure float.

This paper is related to the rapidly growing body of studies on FX intervention. Adler and Tovar (2011) examine the intervention for Latin American countries, and Frankel (2019) recently labels emerging markets' FX policy as "systematic managed floating". However, both papers assume that the central banks intervene in the exchange rate linearly in response to the driving indicators. Our analysis is based on the *nonlinear* property of central banks' FX intervention behavior. Related literature such as Almekinders and Eijffinger (1996) and Ito and Yabu (2007) derive the optimal central bank intervening behaviors and estimate their reaction function using nonlinear models and Japanese daily intervention data. Based on new cross-country daily FX intervention data, Fratzscher et al. (2019) demonstrate the nonlinear property by exploiting a Logit model to estimate the FX intervention function. They find that exchange rate misalignment from the long run trend is an important factor.[6] However, for most countries, including China, daily FX intervention data is not available. Based on the publicly available monthly data from the PBC's balance sheet, our paper provides a simple empirical approach to examine the central bank's nonlinear FX intervention behavior.

Our paper contributes to the theoretical studies on the structural macroeconomic model with FX policy and capital controls. Traditionally, the augmented Taylor rule has been one of the simple linear rules imposed by macro-economists since Taylor (2001). Some following studies such as Monacelli (2001), Benigno (2004), Lubik and Schorfheide (2007), and Adler et al. (2018) incorporate such a linear rule into a DSGE model. However, empirical evidence suggests a central bank's FX intervention function should be nonlinear since the central bank may not choose to intervene until the exchange rate fluctuations go beyond their tolerance. There are also some theoretical studies on FX intervention, such as Chang et al. (2015) and Prasad (2018), but they only study the case of firmly fixed vs. pure floating exchange rate regimes, without any discussion on the intermediate exchange rate regimes such as managed floating. Our paper incorporates managed floating into a structural open macroeconomic model to study how FX policy would affect macroeconomic performance.

[6] Fratzscher et al. (2019) assumes that the central bank react symmetrically to positive and negative misalignment while our paper finds asymmetric reactions of the central bank when the exchange rate substantially depreciates or appreciates.

This paper is also related to the target zone literature such as Krugman (1991), Bertola and Caballero (1992) and Bertola and Svensson (1993). They also build a nonlinear model to discuss exchange rate dynamics for a given band. But managed floating does not normally have a clear band. Therefore, the market expectation may not adjust as in the target zone and pull the exchange rate back when it approaches to the band. Instead, the central bank's FX intervention, which is the focus in this paper, plays a more important role when the exchange rate fluctuates beyond the central bank's tolerance of flexibility.

The paper is structured as follows. Section 2 provides some institutional background on RMB exchange rate policy and our data source. Section 3 documents the empirical patterns regarding the RMB exchange rate regime and the central bank's FX intervention rules. Section 4 incorporates the managed floating exchange rate regime into a structural macroeconomic model using the occasional binding constraint on exchange rate movements. Section 5 concludes with future extensions.

2 Institutional background and data

We start this section by describing recent RMB exchange rate policies. Our focus on RMB exchange rate policy is the recent *managed floating* exchange rate regime.[7] Based on the data publicly available from PBC and Bloomberg, we documents some stylized facts of the central bank's FX intervention that motive our empirical strategies in the next section.[8]

2.1 A brief primer on RMB exchange rate policy

China became the world's largest exporter in international trade in 2009, and China's currency, the RMB, has become more widely accepted in international transactions. As RMB plays an increasingly important role in international trade and finance, it is crucial to understand how China's central bank conducts its exchange rate policy, which can have an impact on the global economy and the transmission of global financial cycles (Obstfeld et al., 2018).

Figure 1 plots the official RMB/USD exchange rate and indicates the exchange rate regime reform dates. The RMB had been effectively pegged to the U.S. dollar at the rate of 8.28 from 1997 until 2005. In July 2005, China announced a switch to a new exchange

[7]See Clark (2017) and Das (2019) for more detailed summary of China's exchange rate regime reform and institutional details of its managed floating exchange rate regime.

[8]Nevertheless, our empirical methodology and modelling strategies could be applied to a broader set of countries that manage their exchange rates, e.g., the emerging market economies in Frankel (2019) and Fratzscher et al. (2019).

rate regime, *managed floating*. Since that time, the RMB/USD exchange rate has faced substantial appreciation pressure and was managed heavily to gradually appreciate against the U.S. dollar. During the 2008-2009 global financial crisis (GFC), the RMB was re-pegged to the U.S. dollar.

INSERT FIGURE 1 HERE

In June 2010, China allowed the RMB exchange rate to regain some flexibility. After then, the RMB/USD exchange rate exhibited an appreciation trend until the market sentiment turned in 2014. In 2015, PBC implemented several reforms to make the RMB exchange rate more market-oriented. Meanwhile, the Federal Reserve started to quit quantitative easing and raise the interest rate. As a consequence, the RMB depreciated dramatically. PBC intervened in the market forcefully from 2015 to 2016 to prevent large and persistent RMB depreciation. See Appendix A and Das (2019) for more institutional details.

2.2 Data

The primary data we use for FX intervention is the *funds outstanding for foreign exchange* on the PBC's balance sheet. Similar to international reserves, this captures most of the central bank's FX intervention behaviors. It is monthly data from June 2010 to August 2017. We choose this sample period for the following reason: Even though China announced a switch to a managed floating regime in July 2005, it maintained a tight control over RMB/USD exchange rate appreciation (crawling peg) and re-pegged to the U.S. dollar during the 2008 global financial crisis. It was only after June 2010 that China started to substantially increase the flexibility of the RMB exchange rate. Therefore, we focus on the recent period of managed floating regime.

We use the central bank's funds outstanding for foreign exchange as the primary measure of FX intervention for two main reasons: First, this measure is denominated in local currency (RMB) so we do not need to estimate the compositions of reserves in order to account for valuation effects; Second, if we used the foreign reserve, the changes might stem from the interest earned on the reserve holdings rather than FX intervention (Calvo and Reinhart, 2002).[9] Figure 2 plots the change in the funds outstanding for foreign exchange, scaled by the monetary base $M0$.[10]

INSERT FIGURE 2 HERE

[9]The better way to capture FX intervention is using higher frequency (daily) data, however, given the data limitation, monthly data is the best we can obtain not only for China but also for most emerging market economies.

[10]A similar measure of FX intervention strength has been used in Frankel (2019) who studies the FX intervention of the central bank in Turkey.

We can see a clear pattern from Figure 2 that the central bank does not intervene in the foreign exchange market in some episodes; yet the scale of FX intervention jumps to a large number in a short period of time, which indicates that the intervention may not follow a linear rule. From late 2010 to the first half of 2011, there was strong FX intervention to prevent RMB appreciation. From the second half of 2011, the central bank's FX intervention started to declined; except for some very short periods of purchasing reserves, the central bank's FX intervention was very weak. After 2014, capital outflow pressure forced the central bank to sell foreign reserves to prevent exchange rate depreciation.[11] From late 2016 onwards, the central bank's FX intervention subsided to around zero.

Another important data source is the RMB exchange rate. Note that the Chinese RMB is mainly traded in two markets: the onshore market in Shanghai (also called CNY) and the offshore market in Hong Kong (also called CNH).[12] We collected exchange rate data from both markets. For the onshore market, we collected data from the China Foreign Exchange Trade System (CFETS). In the onshore market, the RMB/USD exchange rate is restricted by the PBC's exchange rate policy, such as the massive intervention when the exchange rate experienced high depreciation/appreciation pressure. On the other hand, the offshore market has enjoyed much freedom of trading, with no explicit trading bands or FX intervention. Non-deliverable forward (NDF) contracts are commonly used for currencies that are not fully convertable, and represent the financial markets' expectation of currency depreciation/appreciation. We collected the monthly data of 1-year RMB/USD NDF rate in the Hong Kong market because this forward contract has been mostly actively traded. We also collected the 3-month NDF rate and spot CNH rate for robustness checks.

This paper focuses on FX intervention through purchases/sales of foreign reserves, which are the most important toolkit for a central bank. As studied in Frankel (2019) and Fratzscher et al. (2019), central bank FX intervention through changes of reserves is common and effective in EMEs. In the case of China, PBC's purchases and sales of reserve assets are the main method to stablize the RMB exchange rate.

[11]As a result of the FX intervention, China's reserve assets fell by 321 billion USD $ in the second half of 2015 and continued to drop by 443.7 billion USD $ in 2016.

[12]See Shu et al. (2015) for a detailed study on the onshore and offshore RMB markets.

3 Empirical evidence: managed floating and nonlinear FX interventions

In this section we first use the structural break test on the FX intervention following Bai and Perron (1998, 2003)'s methods to prove that there are regime changes. Then, we employ a Markov regime switching model to identify the central bank's FX intervention behavior. We further study the drivers of FX interventions and find that exchange rate deviation from a long run trend is in the central bank's consideration. We conclude this section with a series of robustness tests.

3.1 Structural break test on FX interventions

Some emerging market economies in Latin America (such as Chile, Colombia, Mexico) have a rule-based FX intervention policy, and the intervention is triggered when the exchange rate hits a certain value (Adler and Tovar, 2011; Kuersteiner et al., 2018). However, most central banks, including China's PBC, neither have clearly announced explicit rules for FX intervention nor release their intervention information to the public. Therefore, to explore the detailed managed floating mechanism deployed, we study when and how the central bank reacts to exchange rate fluctuations using real data from foreign exchange markets. Another issue is that we do not have access to daily FX intervention data, in which some of the observations are zero and it is easy to identify the nonlinear property of FX interventions. However, it is not likely to find zero interventions in lower frequency data and some econometric methods are needed. Hence, structural change models can help us identify strong and weak intervention episodes.

We adopt Bai and Perron (1998)'s test of structural breaks on the mean of FX intervention which is measured by the change of *funds outstanding for foreign exchange*. Bai and Perron (2003) provides the estimators, test statistics, and efficient algorithms for a linear model with multiple possible structural breaks at *unknown* dates.[13] Based on the sequential test, l versus $l + 1$ breaks and critical values computed, there are three breaks, and the estimated means of FX intervention are listed in Table 1.

INSERT TABLE 1 HERE

Table 1 shows that there is a very clear pattern of positive and negative FX intervention, where positive (negative) FX intervention means the central bank buying (selling) reserves to prevent the exchange rate from appreciation (depreciation). Furthermore, there is a

[13] This is different from the classic structural break test of Chow (1960) which is based on *known* dates.

period when the central bank did not significantly intervene in the FX market. The four different regimes are as follows: (1) From June 2010, the central bank significantly increasing their holdings on foreign assets until September 2011. In that period, the intervention is positive because the RMB/USD exchange rate is on an appreciation trend and the PBC did not want the currency to appreciate too quickly; thus they kept on purchasing foreign assets (accumulating foreign reserves). (2) From October 2011 to November 2012, the RMB started a two-way fluctuation, and the central bank's FX intervention was very weak and not statistically significantly different from zero. (3) From December 2012 to April 2014, the PBC switched to strong positive FX intervention because this was a short period of RMB appreciation, partly due to the strengthening of China's economy and a weak value of the U.S. dollar. (4) PBC turned to strong negative FX intervention after May 2014.[14] This is due to the "taper tantrum" of late 2013 when Federal Reserve Chairman Ben Bernanke announced the intention to begin phasing down U.S. quantitative easing. However, large scale of purchasing foreign assets started until 2015.[15]

3.2 Regime switching of FX interventions

Structural break tests and regressions have shown that there are strong and weak FX intervention episodes; however, the models are a better fit for cases in which regimes last for a reasonable period. As we observed from Figure 2, FX policy regimes may be temporary and there might be regime switches. In this section, we study the patterns of strong and weak FX intervention with the consideration that regimes may be temporary. In other words, it is likely that the regime flips back and forth in a short period of time. Therefore, we use a Markov regime switching model, which assumes that the same regime can return in a later period.

We run a three-state Markov regime switching model on the central bank's FX intervention, and the estimated results are reported in Table 2. The central bank buys and sells significant foreign reserves to prevent large fluctuations in the RMB exchange rate, in Regime 1 and Regime 2, respectively. In the third regime, Regime 3, the t-Statistic shows that FX intervention is insignificantly different from zero and we can refer it as a

[14]This is consistent with the findings in Das (2019) which claims "market sentiment turned in 2014 toward a rising sense that the RMB was becoming overvalued and intervention turned from FX purchases to growing sales."

[15]It would be more intuitive if the new regime starts from the mid 2015 when the PBC initiated the RMB reform. However, since structural break tests and regressions are more likely to generate persistent regimes, the classification picks weak selling periods in 2014 as well. The regime switching model we propose in the next section solves such issue.

weak FX intervention regime. Moreover, Figure 3 plots the corresponding smoothed regime probabilities. We can see that Regime 1 presents similar results as the structural breaks estimation, and it captures both intensive foreign assets purchasing episodes from mid 2010 to late 2011 and from late 2012 to early 2014, as identified in Table 1. Meanwhile, the intensive sales of foreign reserves periods in 2015 and 2016 are well captured by Regime 2. Besides the period of 2011-2012, the model also identifies the period during mid 2013 as a weak FX intervention episode, which is consistent with the plotting in Figure 2.

INSERT TABLE 2 HERE

INSERT FIGURE 3 HERE

3.3 The drivers of regime switching: tolerance of flexibility

We have shown that the central bank intervenes in the FX market in a nonlinear manner: sometimes the central bank intervenes heavily while at other times it remains largely inactive. So, the next question is: what are the drivers behind the central bank's FX intervention behavior?

Based on the existing FX intervention literature, "fear of floating" is behind the central bank's FX policy.[16] Central banks in EMEs might worry about large exchange rate fluctuations. The empirical studies such as Neely (2008), Fratzscher et al. (2019) and Frankel (2019) show that central banks are likely to intervene when the exchange rate deviates from both its long run trend and the its previous value. Thus, we choose both as the explanatory variables in studying the central bank's intervention behavior.

In China, as in many other emerging market economies, the exchange rate is heavily managed (together with central parity and trading bands), and capital controls are imposed, so the official exchange rate in the onshore market may not truly reflect the market equilibrium or anticipations. This is a standard endogeneity issue in empirical tests. However, China has an active Hong Kong offshore RMB foreign exchange market (CNH market) that can better capture market supply and demand of its currency, as well as financial markets' expectations on future appreciation or depreciation. It could be regarded as the free-market exchange rate if the central bank had lifted its FX interventions. We use the 1-year RMB/USD NDF rate as the main measure of exchange rate. For robustness tests later on, we also use the 3-month NDF rate (3M NDF) as well as the offshore spot exchange rate (CNH).

Specifically, we calculate the RMB/USD exchange rate trend by taking the previous

[16]From a theoretical point of view, there are several reasons why central banks want to limit exchange rate fluctuations. See Calvo and Reinhart (2002), Benigno et al. (2016), etc.

12-month moving average of the corresponding exchange rates, namely the 1-year NDF rate, 3-month NDF rate, and the spot CNH rate, respectively. Then, we plot the density distributions of those deviations based on Regime 1 (strong FX purchases), Regime 2 (strong FX sales), and Regime 3 (weak FX intervention) identified by the previous Markov regime switching results. Results are reported in Figure 4.

INSERT FIGURE 4 HERE

Both 1Y NDF and 3M NDF present a clear pattern that exchange rate deviations from its trend are well separated by Regime 1, Regime 2, and Regime 3, respectively. In the strong FX purchase period (Regime 1) when the central bank buys reserve assets, the exchange rate deviation from the trend is around negative 2%, which means that the exchange rate has been appreciating relative to the trend. Conversely, in the strong FX sales period (Regime 2) when the central bank sells reserve assets, the exchange rate deviation is around 5%. For the weak intervention regime, Regime 3, we can see that the mode of exchange rate deviation is around 0, which means that the central bank will not intervene when the deviation is small and within the tolerance zone. This interesting finding indicates that the intervention is not only *nonlinear*, but also *asymmetric*. The results for CNH also indicates a good separation between the two strong FX intervention regimes, but the density of deviation in the weak FX intervention is a little bit more disperse. This indicates that even if the spot market has a large deviation, the central bank may choose not to intervene since they puts more weight on forward exchange rates, which are better measures of markets' expectations for future exchange rate movement in a period.

Based on these findings, we can define the central bank's *tolerance of flexibility* as the thresholds beyond which the central bank will switch from a weak FX intervention regime to a strong FX intervention regime – either strong FX purchases or FX sales. For example, a glance of Figure 4 finds that if the exchange rate appreciates (depreciates) from its trend by 2% (5%), the central bank would switch into a strong FX purchases (sales) to prevent further exchange rate fluctuations.[17]

It is possible that the central bank will also react to the short run deviation of the currency. This variable is also considered in Frankel (2019) where he studies the systematic linear FX intervention of managed floating countries. Hence, we plot the distribution of the monthly log difference of exchange rate (first difference) in the strong and weak intervention states. The upper panel of Figure 5 plots the results for 1 year NDF, 3 month NDF, and CNH, respectively. The graphs show that the distributions for the short run deviation are

[17]We also conduct threshold regressions to quantitatively examine the central bank's tolerance of flexibility. Details are discussed in Appendix B.

more clustered compared to the long run deviations. In particular, the distributions are very similar among the strong FX purchasing regime (Regime 1) and weak FX intervention regime (Regime 3), which indicates that the central bank may not be sensitive to short run deviation when implementing strong FX purchases. We further check the NDF rate's deviation from the official rate, which is a measure of the market's expectation for RMB appreciation/depreciation. The results are shown in the lower panel of Figure 5. The three density plots are weakly separated. For a robustness check, we also control this variable in the empirical estimation of determinants for regime switches.

INSERT FIGURE 5 HERE

In summary, we find that the FX intervention in China does not follow a linear rule: when the market has a strong pressure of deviation from the trend, the central bank steps in and buys or sells foreign assets. Otherwise, the central bank stays largely inactive. Furthermore, the tolerance of flexibility is different when the central bank faces different directions of exchange rate deviation, with a higher tolerance for depreciation.

3.4 Estimations on the intervention reaction function

So far, we have focused on the nonlinear FX intervention behaviors instead of a concrete central bank reaction function. In this section, we employ multinomial probit (MNP) models to check how important the previous exchange deviation variables are in affecting the FX intervention. The equation is as follows:

$$\Pi_t(Y) = \text{MNP}(e_t - e_{trend}, e_t - e_{t-1}, e_t - e_{official}) \tag{1}$$

where Y is the categorical variable which takes into account all regimes, including the weak FX intervention regime (Regime 3, the default option), strong FX purchase regime (Regime 1), and strong FX sale regime (Regime 2). The regressions are estimated using a multinomial probit (MNP) procedure that imposes the constraint that the three regimes are mutually exclusive and exhaustive. We treat the weak FX intervention regime, Regime 3, as the baseline option, and the multinomial regression estimates the chance of strong FX purchase regime (Regime 1) or strong FX sales regime (Regime 2), relative to the Regime 3. For the explanatory variables, $e_t - e_{trend}$ is the percentage deviation of exchange rate from its trend, and $e_t - e_{t-1}$ is percentage deviation of exchange rate from the previous period. Besides, we check if the deviation of NDF from the official rate ($e_t - e_{t-1}$) also plays a role.

The results are summarized in Table 3.[18]

INSERT TABLE 3 HERE

Based on the results in Table 3, we can see that the deviations from trend are statistically significant in all regressions, and the signs are consistent with our expectation: when the exchange rate appreciates relative to the trend, the central bank is more likely to purchase foreign assets, and vice versa for the deprecation side.

Results for the short run deviations indicate that such variable may not be a robust driver of FX intervention, since column (2) and (4) show either opposite or insignificant estimation coefficients. For the deviations from the official rate, although it shows some significance in the upper panel, the significance disappears when adding the long run deviation in the lower panel. However, the long-run deviation still retains significance. Overall, we find that the long run deviation plays an important role on the FX intervention.[19]

3.5 Currency basket

In the baseline empirical tests, we focus on the RMB/USD exchange rate. As stated in the PBC's official announcement, the RMB is managed with reference to a currency basket. Although some studies, such as Ilzetzki et al. (2019), show that the anchoring currency of the RMB is still the USD, it would be important to see whether our results hold if we consider a basket of currencies. At least in policy circles, it seems that the big debate post-2015 has been the extent to which China cared about the currency basket vs. the dollar rate. Thus, it would be interesting to explore the currency basket.

We follow the methods in the literature to calculate the weights of currencies in the basket. The main methods we use are as the same as Frankel and Wei (2007) and Frankel and Xie (2010): we run the regression of log change of the RMB exchange rate on a bunch of other currencies, namely U.S. dollar, euro, Japanese yen, and Korean won, to get the weights of the four currencies.[20] Since our data span from 2009 to 2017 and China has undergone some institutional reforms as outlined in Section 2, we calculate the weights in three sub-periods: Period 1 (2009.06-2010.06), Period 2 (2010.07-2015.07), and Period 3 (2015.08-2017.08). The weights are summarized in Table 12 in Appendix D and we calculate the RMB index accordingly. Then we replace the RMB/USD rate with the RMB index and run the same multinomial probit models. The results in Table 13 show that the long run

[18] We also checked other specification of intervention reaction function similar to Frankel (2019), instead of using the identified intervention regimes. The results are in Appendix C.

[19] We also run the same regressions for long run NDF deviations from its 6 month trend; the results are robust.

[20] See Appendix D for details.

deviation remains robust, and none of the short run deviations are significant.

3.6 Monetary policy and managed floating

Next, the natural question is: what is the implication for China's monetary policy under the managed floating exchange rate regime? We firstly estimate the following China's monetary policy rule bas on the extension of Chen, Ren and Zha (2018). The regression equation is:

$$\triangle M_t = \beta_0 + \beta_m \triangle M_{t-1} + \beta_\pi(\pi_{t-1} - \pi^*) + \beta_x GDPgrowthgap_{t-1} + \beta_e(e_{t-1} - e_{official,t-1}) + \epsilon_{m,t} \tag{2}$$

Where M is the M2, π is the inflation rate, x is the GDP growth gap (defined as the gap between GDP growth rate and its target), e is the 1-year NDF RMB/USD rate, and $e_{official}$ is the onshore RMB/USD exchange rate. The results are in the following table:

INSERT TABLE 6 HERE

As we can see from the above table, the central bank's response to exchange rate deviation is just statistically significant at 10% level. We have shown that the exchange rate is an important part in Chinese monetary policy. Since we have identified strong and weak episodes in the previous section, we are interested in exploring how monetary policy rule behave different given these regimes. We expand Equation 2 and making the exchange rate coefficient β_e to be time-varying by estimating the following equation:

$$\triangle M_t = \beta_0 + \beta_m \triangle M_{t-1} + \beta_\pi(\pi_{t-1} - \pi^*) + \beta_x x_{t-1} + \beta_e(e_{t-1} - e_{official,t-1}) + \epsilon_{m,t} \tag{3}$$

$$\beta_{e,t} = \begin{cases} \beta_{e,A}, & if\ FX\ strong\ purchasing \\ \beta_{e,B}, & if\ FX\ strong\ selling \\ \beta_{e,C}, & if\ FX\ weak\ intervention \end{cases} \tag{4}$$

The results are summarized in the following table:

INSERT TABLE 7 HERE

As we can see from the table above, the coefficient of inflation is similar to the previous table. However, the coefficients of exchange rate deviation are different. Especially during the exchange rate depreciation, the central bank's reaction to exchange rate is negative and statistically significant. It means that central bank would contract its money supply to restrict further exchange rate depreciation. The coefficient is not significant during exchange rate appreciation. In the next section, we will incorporate this extended China's monetary policy rule into a structural macro economic model to further study the managed floating regime.

4 The structural macro model with managed floating

According to the empirical evidence in the previous section, the central bank intervenes in the exchange rate market only when it has deviated from the trend beyond some thresholds. It would be interesting to study how the central bank's nonlinear FX intervention affects the macroeconomic performance and welfare. In this section, we incorporate central bank's non linear FX intervention behavior into a DSGE model, and address the positive and normative aspects of managed floating. In this section we will firstly lay out a baseline open-macroeconomy model, and then examine the full model with financial frictions.

4.1 Model details

Assuming that there are two countries in the economy – home and foreign – we only focus on home country's problem. The asset market is incomplete. Agents can only trade home and foreign bonds besides investing in domestic firms. Following Schmitt-Grohe and Uribe (2003) and Liu and Spiegel (2015), we introduce an adjustment cost of holding foreign bonds; therefore the model generates deviations from uncovered interest rate parity (UIP) because of imperfect substitutions between domestic and foreign assets.

The home country is populated by a continuum of infinitely lived households. Each consumes C_t, chooses labor hours L_t and the holdings of domestic and foreign bonds, B_t and B_t^* to maximize its lifetime expected utility:

$$\mathbb{E}_t \sum_{t=0}^{\infty} \beta^t (lnC_t - \Phi_l \frac{L_t^{1+\eta}}{1+\eta}) \tag{5}$$

subject to the sequence of budget constraints

$$C_t + \frac{B_t}{P_t} + \frac{e_t B_t^*}{P_t} + \frac{\Omega_b}{2}(\frac{e_t B_t^*}{P_t} - \bar{d})^2 \leq w_t L_t + \frac{R_{t-1}B_{t-1}}{P_t} + \frac{e_t R_{t-1}^* B_{t-1}^*}{P_t} + \frac{D_t}{P_t} \tag{6}$$

where the e_t denotes the nominal exchange rate, which is domestic currency per foreign currency. w_t denotes the real wage. R_t and R_t^* denote the nominal interest rate for domestic and foreign bonds, respectively. D_t denotes the nominal dividends received by the household from share ownership of firms. The parameter Ω_b is a measure of the size of portfolio adjustment costs of foreign bonds. $\bar{d}$ denotes the steady state of real foreign bond holdings $\frac{e_t B_t^*}{P_t}$. Based on the first order conditions with respect to B_t and B_t^*, we obtain the generalized UIP equation:

$$1 + \Omega_b(\frac{e_t B_t^*}{P_t} - \bar{d}) = E_t \frac{\beta \Lambda_{t+1}}{\Lambda_t} \frac{1}{\pi_{t+1}} [R_t - R_t^* \frac{e_{t+1}}{e_t}] \tag{7}$$

where Λ_t is the Lagrangian multiplier for the household budget constraint. π_{t+1} is the inflation rate.

There is a continuum of retailers producing a differentiated final goods $Y_t(j)$ using technology:

$$Y_t(j) = \Gamma_t(j)^{\phi}(L_t(j))^{1-\phi} \tag{8}$$

where $\Gamma_t(j)$ is the input of intermediate goods. The intermediate goods are produced using both domestically produced goods and imported goods, with the CES production function:

$$\Gamma_t = [\alpha^{\frac{1}{\epsilon}} \Gamma_{ht}^{\frac{\epsilon-1}{\epsilon}} + (1-\alpha)^{\frac{1}{\epsilon}} \Gamma_{ft}^{\frac{\epsilon-1}{\epsilon}}]^{\frac{\epsilon}{1-\epsilon}} \tag{9}$$

where Γ_{ht} and Γ_{ft} denote the quantity of domestic produced goods and imported goods. ϵ governs the elasticity of substitution between home and foreign goods.

Cost minimizing implies that the relative price of intermediate goods is given by:

$$q_{mt} = [\alpha + (1-\alpha) q_t^{1-\epsilon}]^{\frac{1}{1-\epsilon}} \tag{10}$$

where $q_t = \frac{e_t P_t^*}{P_t}$ is the real exchange rate. Cost-minimization implies that

$$q_t = \left[\frac{1-\alpha}{\alpha}\right]^{\frac{1}{\epsilon}} \left[\frac{\Gamma_{ht}}{\Gamma_{ft}}\right]^{\frac{1}{\epsilon}} \tag{11}$$

The final goods producer solves the cost minimization problem and they set the price in each period following Rotemberg pricing.

$$Max_{P_t(j)} E_t \sum_{k=0}^{\infty} \beta^k \frac{\Lambda_{t+k}}{\Lambda_t} [(\frac{P_{t+k}(j)}{P_{t+k}} - v_t) Y_{t+k}^d(j) - \frac{\Omega_p}{2} (\frac{P_{t+k}}{\pi P_{t+k-1}(j)} - 1)^2 C_{t+k}] \tag{12}$$

where $Y_t^d(j) = [\frac{P_t(j)}{Pt}]^{-\theta_p} Y_t$, given that θ_p is the elasticity substitution between differentiated retail products. Ω_p measures the size of price adjustment costs and $\hat{\pi}$ is the steady state inflation rate. Solving for the optimal pricing decision, we can then derive the Philips curve.

Some of the domestically produced goods are exported to the world economy. We assume that the demand function for exports is related to the term of trade and income of the foreign country:

$$X_t = \left(\frac{P_t}{e_t P_t^f}\right)^{-\eta_f} Y_t^* \tag{13}$$

where Y_t^* is the foreign country's output. η_f is the export demand elasticity. We assume that both Y_t^* and foreign interest rate R_t^* follow an AR(1) stationary process:

$$lnY_t^* = (1-\rho_y)lnY^* + \rho_y lnY_{t-1}^* + \sigma_y \epsilon_{yt} \tag{14}$$

$$lnR_t^* = (1-\rho_r)lnR^* + \rho_r lnR_{t-1}^* + \sigma_r \epsilon_{rt} \tag{15}$$

The home country's current account balance (ca) is defined by the sum of trade surplus and net interest income received from holdings of foreign assets, which is also the change in the country's holdings of foreign bond:

$$ca_t = X_t - q_t \Gamma_{ft} + \frac{e_t(R_{t-1}^* - 1)B_{t-1}^*}{P_t} = e_t \frac{B_t^* - B_{t-1}^*}{P_t} \tag{16}$$

The real GDP is defined as the sum of consumption and net exports:

$$GDP_t = C_t + X_t - q_t \Gamma_{ft} \tag{17}$$

Furthermore, following Chang et al. (2015), we assume that Y_t, Γ_{ft}, Γ_{ht}, C_t, ca_t, w_t, B_t, B_t^*, X_t, D_t are all detrended by Z_t, a labor-augmenting technology which grows with a rate λ_z .

The model is closed with an equation which specifies the central bank's monetary policy.

4.2 Nonlinear intervention and the occasional binding constraint

In this section, we take the model above to study the central bank's managed floating regime based on occasional binding constraints.

In the occasional binding constraint setup, the model has two types of regimes: reference and alternative. When the constraint is non-binding, the model is in the reference regime; otherwise, the model switches to the alternative regime. Following Guerrieri and Iacoviello

(2015), the non-linear model is solved with piecewise linear approximation.

In our setup, we introduce two constraints on the exchange rate since it fluctuates in two ways:

$$\gamma_{low} \leq \hat{g_{et}} \leq \gamma_{high} \tag{18}$$

where g_{et} is defined as e_t/e_{t-1}, which is the growth of nominal exchange rate. $\hat{g_{et}}$ is the log deviation from its steady state, and γ is the largest deviation that the central bank can tolerate. Since the model corresponds to the quarterly data, which indicates the deviation of the exchange rate from its value 3 months ago. We regard it as the approximated theoretical counterpart of the exchange rate deviation from its trend discussed in our empirical studies.

Based on our previous results on the tolerance of flexibility, we feed -2% into the constraint parameter γ_{low} on the appreciation side, and 5% into γ_{high} on the deprecation side.[21] When either of these constraints binds, the central bank would intervene in the FX market to make sure the exchange rate satisfies the constraint. In this case, we are in the alternative regime.

When neither of the constraints binds, we are in the reference regime which corresponds to the pure floating regime. In such regime, the central bank does not respond to the changes of exchange rate. Instead, the monetary policy follows a Taylor rule (Chang et al., 2015): $\hat{R}_t = 1.5\hat{\pi}_t + 0.5G\hat{D}P_t$, where $\hat{R}_t$, $\hat{\pi}_t$ and $G\hat{D}P_t$ are the interest rate, inflation, and GDP log deviation from their steady states.[22]

4.3 Calibration

The model is calibrated to a quarterly frequency. The statistics for the data are mostly computed from China's 2010 to 2017 data. Table 8 summarizes the parameter values.

INSERT TABLE 8 HERE

The discount factor β is 0.998. The inverse of the Frisch labor supply elasticity η is 2 which implies a Frisch elasticity of labor supply of 0.5, consistent with micro-level evidence (Pencavel, 1986). Φ_l is set to be 13.13 so that the steady-state fraction of labor hours equals 40% of total time endowment. For the import demand elasticity ϵ, we use 1 which is standard in the international economics (Gali and Monacelli, 2005, Chang et al., 2015).

[21] We also tried a symmetric band, and the results remain qualitatively unchanged.

[22] Such a setup is for simplicity. In practice, the monetary policy rule may be different, especially for China. See Chen et al. (2018). We leave this for future extensions.

The export demand elasticity η_f is set as 1.5, consistent with the study by Feenstra et al. (2018). For the technology parameters, we set mean technology growth rate $\bar{\lambda_z}$ to be 1.0185 to match the Chinese real GDP per capita growth. Following Basu (1995), the cost share of intermediate goods ϕ is set to 0.5. Following Chang et al. (2015), we set the shock parameters ρ_r and ρ_y as 0.98 and 0.95, respectively, to capture the long persistent zero lower bound and slow down in the world demand periods. The standard deviations of each shock are set to 1%.

One of the key parameter is the portfolio adjustment cost Ω_b. Following Benigno (2009) and Liu and Spiegel (2015), Ω_b is set as 0.01 in the case of an open capital account. Since China has strong capital controls, we set Ω_b as 0.03.[23]

4.4 Quantitative results

In this section, we discuss the quantitative results. We first evaluate the impulse response functions under foreign interest rate shocks. Results are plotted in Figure 6: the dotted lines are impulse responses of the model with a pure floating exchange rate (without occasional binding constraints), and the solid lines give the results of the managed floating model. Given a negative 0.5% shock in the foreign interest rate, the nominal exchange rate appreciates by around 6% immediately in a floating exchange rate regime. Given a negative 2% bound, the exchange rate growth stays at such level for three periods and then switches to the reference regime.

INSERT FIGURE 6 HERE

Meanwhile, in order to keep the exchange rate growth bounded, the central bank has to lower the domestic interest rate so that it makes domestic borrowing more attractive than foreign borrowing. As the capital inflow drops, it curbs the exchange rate's further appreciation. With a flexible exchange rate regime, the large nominal appreciation pass–through to the price level and the inflation drops. However, when it comes to the managed floating regime, further reduction of the domestic interest rate lowers prices and it dominates the pass–through effects so that inflation experiences an increase immediately after the foreign interest rate shock. Then, as prices adjust due to the appreciation of the local currency, inflation drops until it converges to the reference regime. The managed floating regime shows less volatility in the real exchange rate, and so do exports. Since the interest rate gets to a lower level, it boosts consumption, import, labor, and GDP to a higher level than those in the flexible exchange rate regime. Such income effects also lead to a slightly

[23] We also tested a range for this parameter, and the qualitative results do not change.

lower level of current accounts in the managed floating case.

Next, we move to the case of opening the capital account. Results are reported in Figure 7. Compared to the case under strong capital controls, the duration of being trapped in a lower bound is one period (a quarter) longer. This is because that the exchange rate now appreciates further in the pure floating regime, and the central bank needs to take more effects on FX intervention given the same tolerance. This is consistent with the empirical results in Kuersteiner et al. (2018). Therefore, FX policy and capital controls play complementary roles in stabilizing the exchange rate.

INSERT FIGURE 7 HERE

We then consider the case of both negative and positive foreign interest rate shocks. Figure 8 presents the impulse response functions when we give a -0.5% and 0.5% foreign interest rate shock at the Period 10 and Period 40, respectively. In the case of a positive shock, we assume a higher tolerance on the exchange rate deprecation. Therefore, we can see the constraint binds for a shorter period and all the responses become less persistent.

INSERT FIGURE 8 HERE

Based on the model, we can also conduct a welfare analysis. We simulate the data 1000 times and compute the standard deviations and welfare gains for different models. Welfare gains are computed based on the consumption equivalence measure. Results are reported in Table 9. We can see that moving from managed floating to fully floating improves welfare, since constraining the nominal exchange rate leads to a decrease in macroeconomic stability. Note that If the government cares more about the net exports, e.g., from a Mercantilism's point of view, the managed floating might lead to a higher welfare. See the discussion in Aizenman and Lee (2007) and Bernanke (2017).

INSERT TABLE 9 HERE

Furthermore, opening the capital account may lead to a loss of welfare. Note that in our model the capital control is exogenously imposed as a transaction cost (loss) of holding foreign bonds; although stronger capital controls introduce a greater wedge for the UIP, they also lower foreign bond holdings/capital flows, which in total might improve the welfare. Since our model has both price frictions and incomplete markets when capital account restrictions are alleviated, the analysis is necessarily about second-best policies as discussed in Chang et al. (2015). They depend on the parameter calibration and sources of shocks. Moreover, if there are further financial frictions such as in Jeanne and Korinek (2010) and Davis and Presno (2017), there could be larger welfare gains from capital controls. We study the full fledged models with financial frictions and managed floating in the next subsection.

4.5 Full model with financial frictions

The above model is a simple illustrative theory of how FX intervention would affect macro economy. But in these type of models, due to the double coincidence, there is usually little room for exchange rate intervention. They support the full flexible exchange rate regimes. Therefore we need to extend the model with financial frictions to give some room for central bank's intervention. We extend the baseline model a la Aoki et al. (2018) with financial frictions and currency mismatch. The model details can be found in Aoki et al. (2018).

Specifically, we embed the monetary policy rule that responses to exchange rate into the model. Due to the financial frictions and currency mismatch, exchange rate plays a key role in the transmission of foreign interest shocks. In the model we have a banking sector that borrows in foreign currency but lend in local currency. The policy tools are FX intervention and macroprudential policy (cyclical tax on the foreign borrowing). If the central bank does not react to exchange rate movement, it will follow the standard Taylor rule:

$$i_t - i = (1 - \alpha_i)\,\phi_\pi\,(\pi_t - 1) + \alpha_i\,(i_{t-1} - i) + \varepsilon_t^i$$

However, if the central bank intervenes the FX market, it would follow the below monetary policy rule:

$$i_t - i = (1 - \alpha_i)\,[\phi_\pi\,(\pi_t - 1) + \phi_e\,(g_{et} - g_e)] + \alpha_i\,(i_{t-1} - i) + \varepsilon_t^i$$

The model is solved using the above-mentioned OCCBIN techniques. In particular, we study the positive foreign interest rate shock, and how would that affect the economy under the managed floating exchange rate regime.

First we present the impulse responses in Figure 9 when there is no macroprudential policy (free capital inflows/outflows). To enforce the managed floating exchange regime, the domestic central bank needs to follow the foreign interest rate hike by raising the domestic interest rate. Therefore, it causes a larger drop of output, bank's net worth and capital price, compared to flexible exchange rate regime.

INSERT FIGURE 9 HERE

Then we consider the coordination of macroprudential policy in Figure 10. With the restriction on foreign debt, the central bank only needs to raise the interest rate by a small margin,compared to Figure 9. Thus the key macroeconomic and financial variables will have a lower volatility. If we compare the managed floating with pure float, the output will drop more in the first two/three periods, but is stabilized after 5 period. The external debt, consumption, and inflation have the similar pattern. Therefore, managed floating would allow the economy to restore higher level of macro/financial stability in the medium and long run.

INSERT FIGURE 10 HERE

5 Conclusion

This paper studies FX intervention and the managed floating exchange rate regime. Focusing on the case of China, we find evidence that the central bank's FX intervention policy is nonlinear: it intervenes in heavily when the RMB exchange rate deviates from its long run trend by a large margin and otherwise it keeps inactive. Furthermore, the central bank responds asymmetrically toward depreciation and appreciation, with a higher tolerance for depreciation. We then incorporate this nonlinear exchange rate policy into a DSGE model with occasional binding constraints. Based on the model, we find that, compared to a free floating regime, the managed floating regime generates higher volatility in major macro variables in the face of a negative foreign interest rate shock. Moreover, the exchange rate deviation constraint binds longer when the capital account restriction is removed, which indicates that capital controls and FX policies are complements rather than substitutes. In a full model with financial frictions and currency mismatch, we find that managed floating would lead to higher volatility of output, inflation and capital price in the absent of capital controls. However, with macroprudential policies, it could achieve greater economic and financial stability in the medium/long run, compared to pure float.

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Variable	Coefficient	Std.Error	t-Statistic	Prob.
		2010M06 - 2011M09 – 16 obs		
C	0.065	0.0059	11.14	0.00
		2011M10 - 2012M11 – 14 obs		
C	0.0014	0.0063	0.22	0.82
		2012M12 - 2014M04 – 17 obs		
C	0.037	0.0057	6.58	0.00
		2014M05 - 2017M08 – 40 obs		
C	-0.022	0.0037	-6.02	0.00

Table 1: Identifying break points in China's FX intervention

Variable	Coefficient	Std.Error	t-Statistic	Prob.
		Regime 1		
C	0.036	0.0023	15.81	0.00
		Regime 2		
C	0.0018	0.0026	0.71	0.48
		Regime 3		
C	-0.0013	0.0031	-4.32	0.00
		Non-switching parameter		
β	-0.22	0.22	-0.96	0.34

Table 2: Three state Markov switching estimation

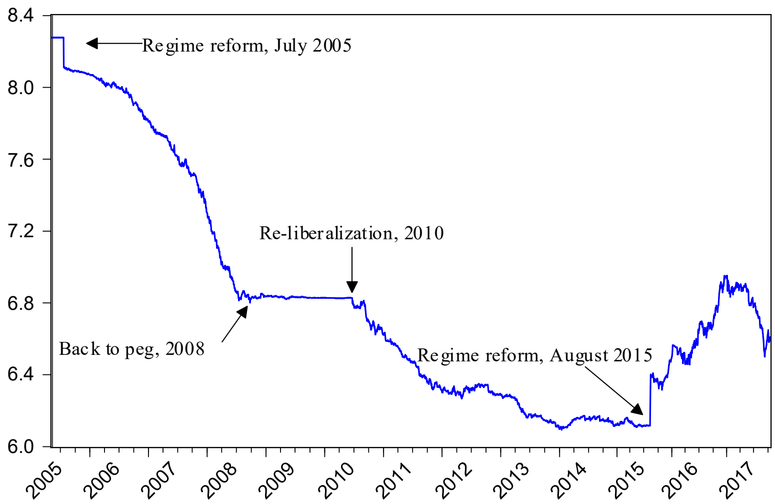

Figure 1: China's exchange rate regime reforms

	(1)	(2)	(3)	(4)
Regime 1 vs. Regime 3				
$e_{t-1} - e_{trendt-1}$	-102.63***	-116.40***		
	(23.65)	(28.03)		
$e_{t-1} - e_{t-2}$		30.31		-33.76
		(31.73)		(32.33)
$e_{t-1} - e_{officialt-1}$			-85.42***	-86.01***
			(18.69)	(19.55)
$\triangle KA_{t-1}$	4.62	4.11	1.62	2.41
	(4.71)	(4.89)	(4.36)	(4.51)
constant	-0.57	-0.71	0.35	0.36
	(0.33)	(0.36)	(0.29)	(0.30)
Regime 2 vs. Regime 3				
$e_{t-1} - e_{trendt-1}$	87.33***	113.17***		
	(22.90)	(29.65)		
$e_{t-1} - e_{t-2}$		-62.03		-4.40
		(35.26)		(27.77)
$e_{t-1} - e_{officialt-1}$			134.53***	135.44***
			(36.05)	(36.91)
$\triangle KA_{t-1}$	-0.25	-1.39	1.28	1.42
	(4.74)	(4.80)	(4.34)	(4.34)
constant	-1.07**	-1.21**	-2.61***	-2.61***
	(0.38)	(0.42)	(0.72)	(0.73)
N	92.00	92.00	92.00	92.00

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 3: Multinominal probit estimation (reaction function)

Currency	USD	EUR	JPY	KRW
Period 1: 2009.06-2010.06				
weights	0.989	0.011	0	0
Period 2: 2010.07-2015.07				
weights	0.923	0.056	0.008	0.013
Period 3: 2015.08-2017.08				
weights	0.792	0.099	0.063	0.036

Table 4: Weights for currency basket

	(1)	(2)	(3)	(4)
Regime 1 vs. Regime 3				
$e_{t-1} - e_{trendt-1}$	-52.52**	-57.49*		
	(18.84)	(22.50)		
$e_{t-1} - e_{t-2}$		10.69		-13.82
		(28.98)		(33.07)
$e_{t-1} - e_{officialt-1}$			-89.19***	-87.39***
			(19.58)	(19.87)
$\triangle KA_{t-1}$	5.02	5.18	1.81	2.18
	(3.94)	(3.98)	(4.46)	(4.57)
constant	-0.06	-0.09	0.56	0.54
	(0.26)	(0.27)	(0.32)	(0.32)
Regime 2 vs. Regime 3				
$e_{t-1} - e_{trendt-1}$	67.21***	82.30***		
	(16.45)	(20.59)		
$e_{t-1} - e_{t-2}$		-47.72		-40.60
		(30.45)		(33.47)
$e_{t-1} - e_{officialt-1}$			133.15***	148.56***
			(33.12)	(36.15)
$\triangle KA_{t-1}$	-0.16	-0.68	3.57	3.13
	(4.29)	(4.32)	(4.52)	(4.53)
constant	-0.74*	-0.78*	-2.95***	-3.27***
	(0.31)	(0.32)	(0.73)	(0.81)
N	91.00	91.00	92.00	91.00

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 5: Multinominal probit estimation: Currency Basket

Coefficient	Estimate	SE	P value
β_0	0.025	0.006	0.000
β_m	0.448	0.111	0.000
β_π	-0.897	0.328	0.011
β_x	0.021	0.169	0.903
β_e	**-0.225**	**0.118**	**0.067**
σ	0.006	0.001	0.000

Table 6: No regime changes in FX interventions: 2009Q2 - 2017Q2

Coefficient	Estimate	SE	P value
β_0	0.025	0.006	0.000
β_m	0.432	0.106	0.000
β_π	-0.862	0.313	0.010
β_x	0.11	0.183	0.552
$\beta_{e,A}$	**-0.162**	**0.175**	**0.363**
$\beta_{e,B}$	**-0.322**	**0.121**	**0.013**
$\beta_{e,C}$	**-0.051**	**0.249**	**0.839**
σ_e	0.006	0.001	0.000

Table 7: With regime changes in FX interventions: 2009Q2 - 2017Q2

Description	Parameter	Value
Households		
Discount factor	β	0.998
Utility weight on leisure	Φ_l	13.13
Inverse of Frisch Elasticity	η	2
Firms		
Price adjustment cost	Ω_p	60
Technologies		
Cost share of intermediate goods	ϕ	0.5
Mean productivity growth rate	$\bar{\lambda}_z$	1.0185
Portfolio adjustment		
Foreign bonds adjustment cost	Ω_b	0.03
International Trade		
Share of domestic goods	α	0.7556
Import demand elasticity	ϵ	1
Export demand elasticity	η_f	1.5
Monetary Policy		
Interest rate resp. to inflation	ϕ_π	1.5
Interest rate resp. to output	ϕ_y	0.5
Shock processes		
Persistence of foreign interest rate shock	ρ_r	0.98
Persistence of export demand shock	ρ_x	0.95
Standard deviation of foreign interest rate shock	σ_r	0.01
Standard deviation of export demand shock	σ_x	0.01

Table 8: Calibrated parameters (Quarterly)

Variable (Std/welfare gains)	with capital controls		open capital accounts	
	Managed float	Float	Managed float	Float
GDP	0.0024	0.00067	0.0037	0.0012
C	0.0054	0.0032	0.0085	0.0053
π	0.0013	0.00091	0.0021	0.0014
L	0.0014	0.0010	0.0023	0.0016
q	0.0052	0.069	0.0088	0.011
ca	0.061	0.059	0.090	0.085
welfare gains	–	0.000026	-0.000094	-0.000015

Table 9: Simulated standard deviations and welfare under alternative regimes

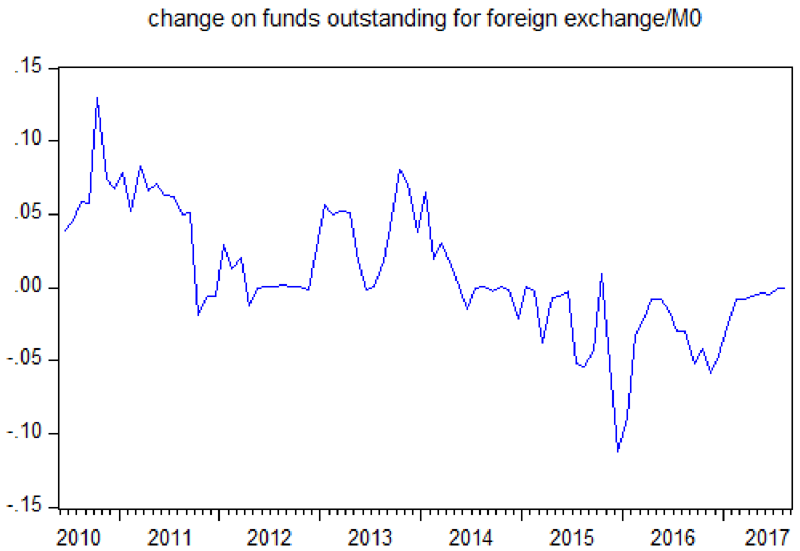

Figure 2: FX intervention

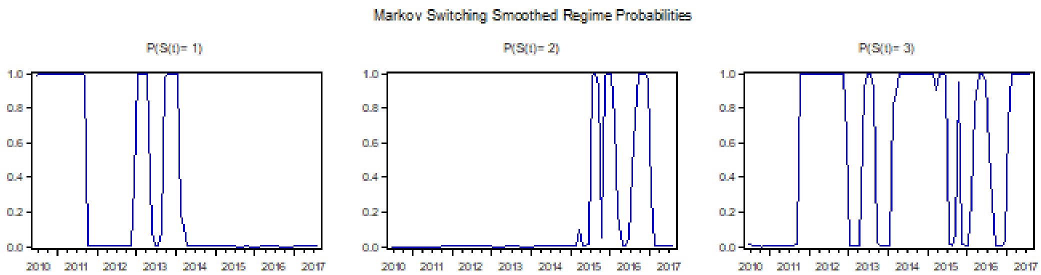

Figure 3: Regime probabilities from three-state Markov switching model

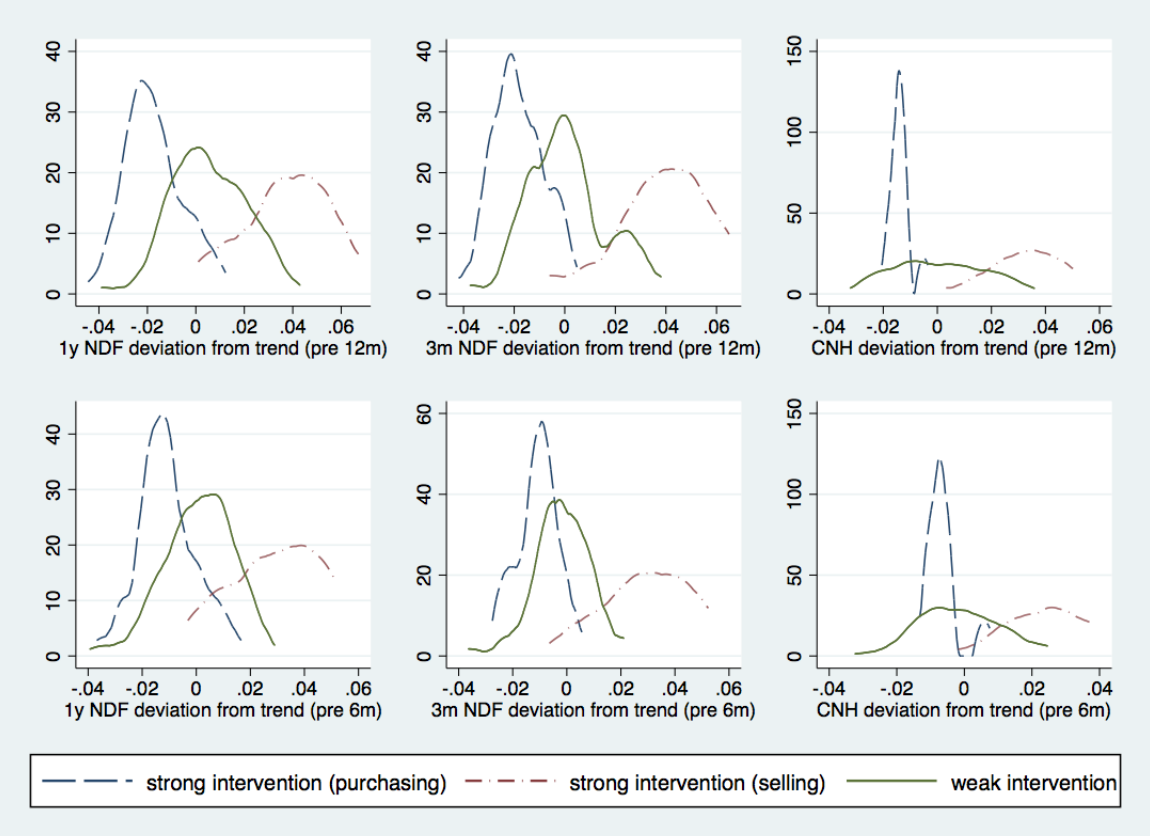

Figure 4: Distributions based on different trends

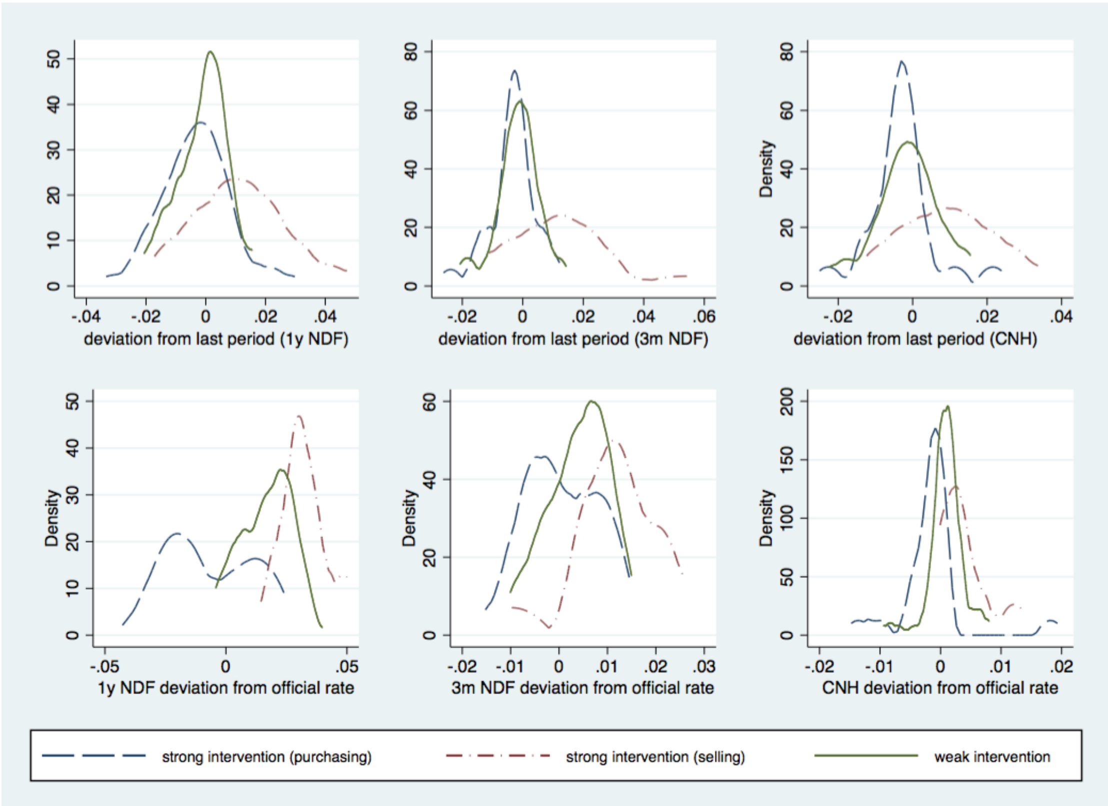

Figure 5: Distributions based on other different deviations

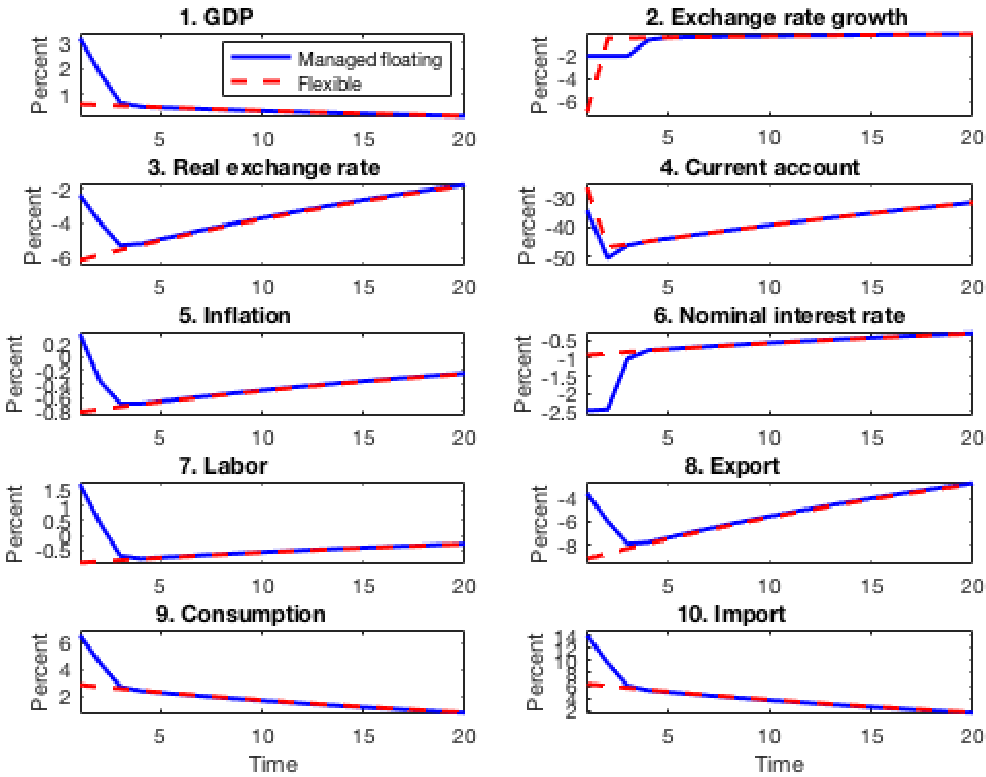

Figure 6: Impulse response function to a 0.5% negative foreign interest rate shock (with capital account restrictions)

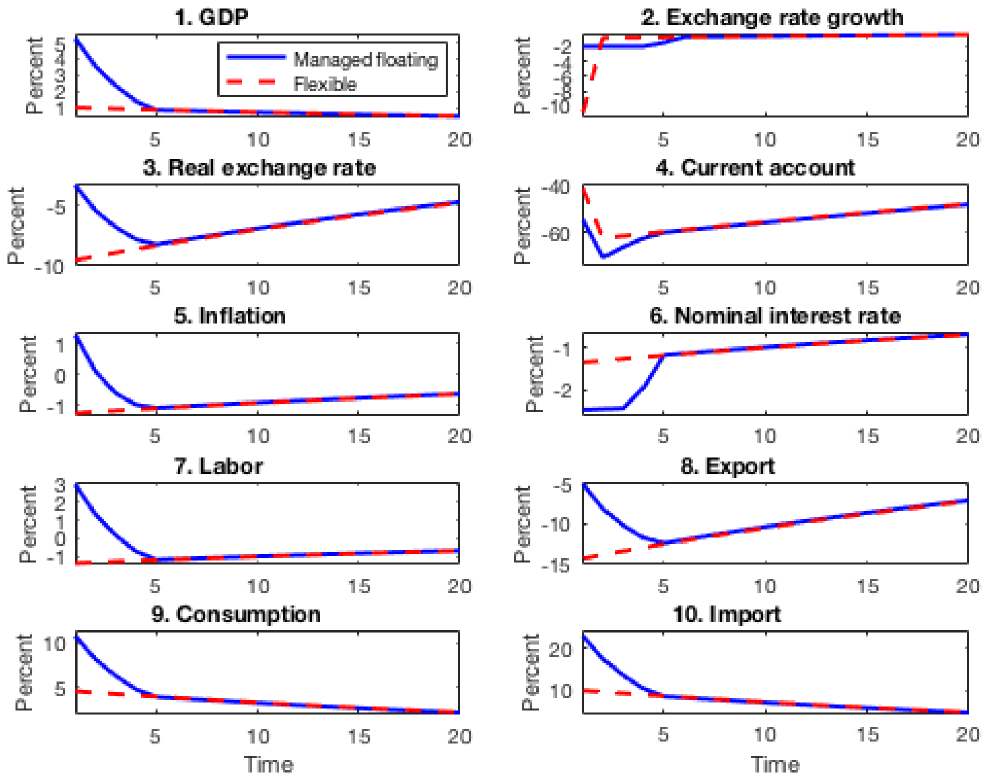

Figure 7: Impulse response function to a 0.5% negative foreign interest rate shock (open capital account)

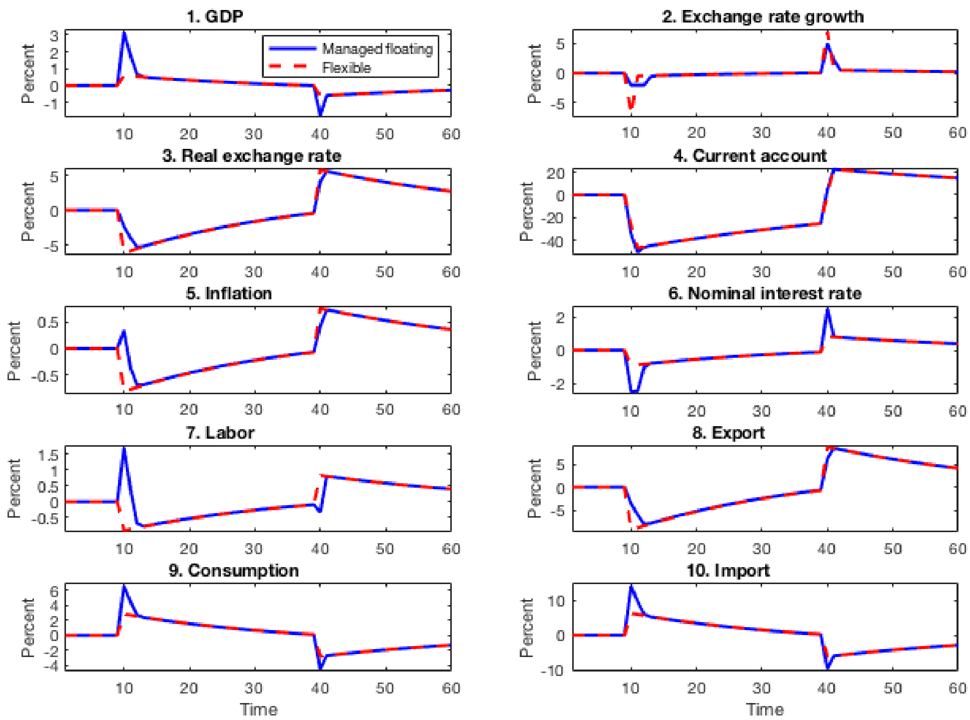

Figure 8: Impulse response function to a 0.5% negative and positive foreign interest rate shock (with capital account restrictions)

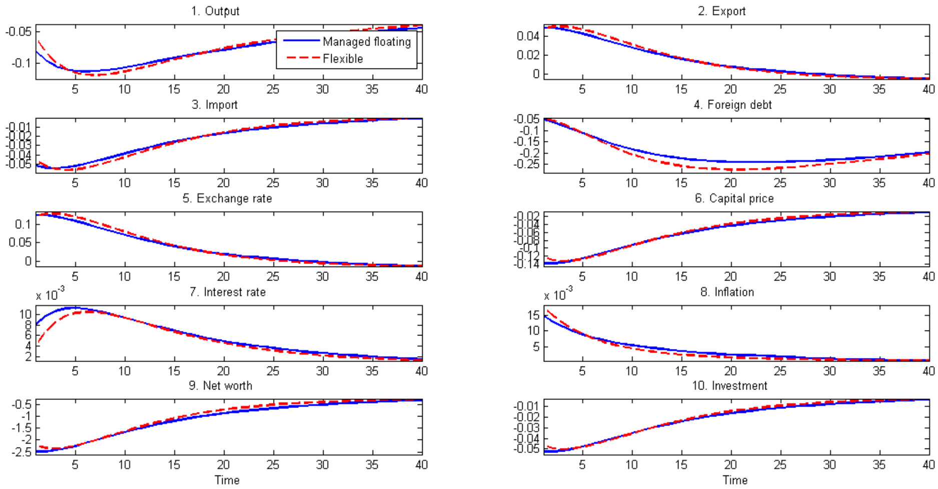

Figure 9: Impulse response function to a 1% positive foreign interest rate shock (without macroprudential policies)

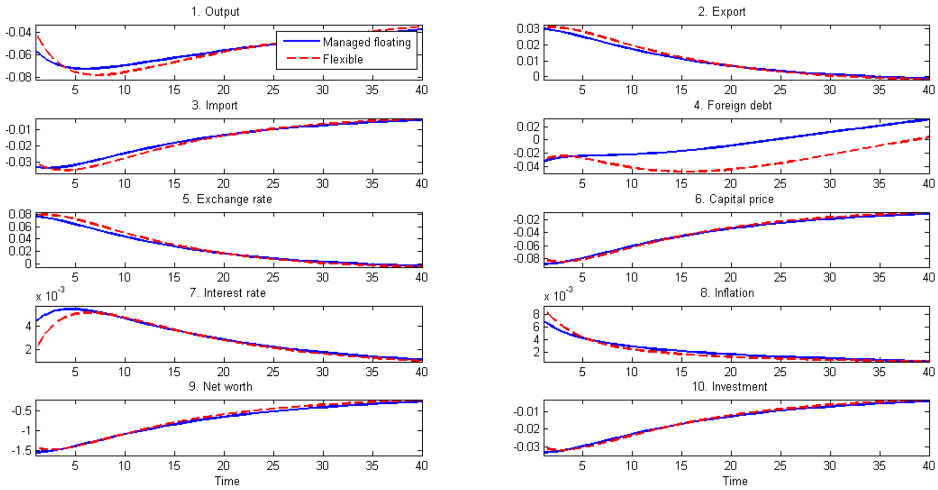

Figure 10: Impulse response function to a 1% positive foreign interest rate shock (with macroprudential policies)

Appendix

A. China's RMB exchange rate policy

This paper focuses on China's RMB exchange rate policy. According to the recent data by the Society for Worldwide Interbank Financial Telecommunication (SWIFT), the RMB ranked as the *fifth* largest global currency by currency activity share (below U.S. dollar, euro, British pound and Japanese yen) and was accepted by more than 100 countries and territories in 2016.[24] As the RMB plays an increasingly important role in international trade and finance, it is important to examine Chinas exchange rate policy.[25] This section provides some institutional details of the RMB exchange rate regime. For more detailed documents, see Sun et al. (2016), Yu et al. (2017) and Das (2019).

China established a nationwide foreign exchange market in 1994 after the unification of the official and parallel exchange markets. After a slight appreciation, the PBC pegged the RMB against the U.S. dollar at the level of 8.28 from 1997 to 2005. In the face of large balance of payments surpluses and internal inflation pressure, on July 21, 2005, China announced a switch to a *managed floating* regime. In the official announcement, PBC would ensure that "the daily trading price of the U.S. dollar against the RMB in the interbank foreign exchange market will be allowed to float within a band of ±0.3% around the central parity published by PBC".[26] The PBC "will make adjustment of the RMB exchange rate band when necessary according to market development as well as the economic and financial situation" and "maintain the RMB exchange rate basically stable at an adaptive and equilibrium level so as to promote the basic equilibrium of balance of payment and safeguard macroeconomic and financial stability." In practice, the PBC announces the central parity rate of the RMB against the U.S. dollar before the opening of the onshore market each trading day. In May 2007, PBC further expanded the daily trading band from ±0.3% to ±0.5% but still maintained a tightly managed RMB/USD exchange rate.

As the global financial crisis (GFC) peaked in the summer of 2008, China became worried about the volatile exchange rate and its potential negative effects on the economy. At the end of 2008, China started to *de facto* repeg to the U.S. dollar at 6.82 within a very

[24] See https://www.swift.com/insights/press-releases/more-than-100-countries-are-now-using-the-rmb-for-payments-with-china-and-hong-kong for details.

[25] It is also important for financial stability in the Asian Pacific region because the co-movement between RMB and other currencies depends on the extent of management of the RMB (Marconi, 2018).

[26] See PBC announcement on July 21, 2005, "Reforming the RMB Exchange Rate Regime". RMB was permitted to fluctuate with a much wider band against the other four major currencies: Euro, Hong Kong dollar, Japanese Yen and British pound, which manifested the single most importance of U.S. dollar in RMB exchange rate regime.

narrow band less than $\pm 0.1\%$. On June 19, 2010, PBC allowed its exchange rate regime to regain some flexibility with the daily trading band $\pm 0.5\%$, later on expanded to $\pm 1\%$ in early 2012 and then to $\pm 2\%$ in early 2014.[27] After a relatively strong appreciation in 2011, the RMB/USD exchange rate exhibited two-way fluctuations from 2012 to 2014, with some moderate appreciation in early 2013. Market sentiment turned in 2014, and RMB faced depreciation pressure. There was a surge in the U.S. dollar on expectations of potential increases in the U.S. interest rate after the Federal Reserve Chairman Ben Bernanke explicitly discussed the taper tantrum. PBC's FX intervention switched to selling foreign reserves to limit RMB/USD depreciation in the summer of 2014.(Das, 2019) On August 11 2015, PBC implemented several reforms to make the central parity more transparent and more market-oriented. Meanwhile, the PBC aimed to stabilize the RMB to a currency basket. As the Fed started to quit quantitative easing and raised the interest rate, there was tremendous depreciation pressure on the RMB.[28] The PBC intervened in the market forcefully from 2015 to 2016 to prevent large and persistent RMB depreciation.

B. Threshold regressions

We have shown that long run deviations of exchange rate, rather than short run deviations, play an essential role in the PBC's FX intervention. To quantitatively examine the central bank's tolerance of flexibility, we adopt a threshold regression model. Using long run deviation of the 1 year NDF as the threshold variable, we use the sequential break test method in Bai and Perron (1998) to determine the number of thresholds. The estimation results are listed in Table 10. Consistent with our expectation, the model identifies three regimes (two thresholds). When the deviation is either lower than -0.82% or greater than 2.56%, the central bank's FX intervention is equal to 0.052 and -0.044, respectively, both of which are significantly different from zero. When the exchange rate deviation falls between these two thresholds, no significant FX intervention is implemented. Hence, the results not only well capture the strong and weak FX intervention in China, but also provide a more accurate calculation of the *tolerance of flexibility*. Furthermore, in terms of long run deviations, we also find that the tolerance of appreciation is lower than for depreciation, which is consistent with the previous distribution plots. The asymmetric tolerance of flexibility might be partially driven by the large RMB depreciation after August 2015. As we see in

[27] See PBC announcement on June 19, 2010, "Further reform the RMB Exchange Rate Regime and Enhance the RMB Exchange Rate Flexibility".

[28] The capital and financial account switched from capital inflows of 346.1 billion USD \$ in 2013 to capital outflows of 51.4 and 485.3 billion USD \$ in 2014 and 2015, respectively. The surge of capital outflow in 2015 was largely due to short-term investment flows.

Variable	Coefficient	Std.Error	t-Statistic	Prob.
$(e\text{-}e_{trend}) < -0.82\%$				
C	0.052	0.0030	10.39	0.00
$-0.82\% \leq (e - e_{trend}) < 2.56\%$				
C	0.00035	0.0038	0.090	0.93
$(e\text{-}e_{trend}) \geq 2.56\%$				
C	-0.044	0.0070	-6.32	0.00

Table 10: Threshold regression

Section 2, after August 11, 2015 PBC conducted a major RMB exchange rate reform, which triggered a surge of capital outflows and depreciation pressure for the RMB exchange rate. PBC intervened heavily in the FX market in that period to prevent further depreciation of the RMB.

C. Regime switching on the reaction function

We estimate the central bank's FX intervention reaction function using a two state regime switching model following Frankel (2019):

$$\frac{intervention}{M0} = c(S_t) + \alpha(S_t)(e_t - e_{trend}) + \beta(S_t)(e_t - e_{t-1}) + \epsilon_t,\ \epsilon_t \sim N(0, \sigma^2)$$

One caveat for running a regime change model for this equation is that the reaction parameters α and β are two states (strong and weak), but the constant term would possibly be three states (strong purchasing, strong selling, and weak). Hence, the estimation of constant term may be biased. However, it would be interesting to check how the reaction parameters are different from states.

Figure 11 plots the smoothed regime probabilities. Compared to the regimes in Figure 3, we can see that the first regime in Figure 11 includes all of the episodes of strong purchasing regime and some of the episodes of strong selling regime. Generally, it captures well the strong and weak intervention episodes. Table 11 reports the estimation results. We can find that the long run deviation is negatively significant in both regimes, which means the central bank purchases (sells) foreign assets when the exchange rate is below (above) its trend. In the strong intervention regime, the reaction to long run deviation is equal to -1.82, which is much greater than the value in the other regime. Meanwhile, the short run deviation does not show any significance in either regime, which validates that it is not the

Variable	Coefficient	Std.Error	t-Statistic	Prob.
		Regime 1		
C	0.027	0.0036	7.55	0.00
e-e_{trend}	-1.82	0.15	-12.17	0.00
$\triangle e$	0.27	0.30	0.89	0.37
		Regime 2		
C	-0.0044	0.0033	-1.32	0.19
e-e_{trend}	-0.65	0.19	-3.39	0.00
$\triangle e$	-0.14	0.33	-0.41	0.68

Table 11: 2 state Markov switching estimation (reaction function)

primary concern for the central bank when implementing FX interventions.

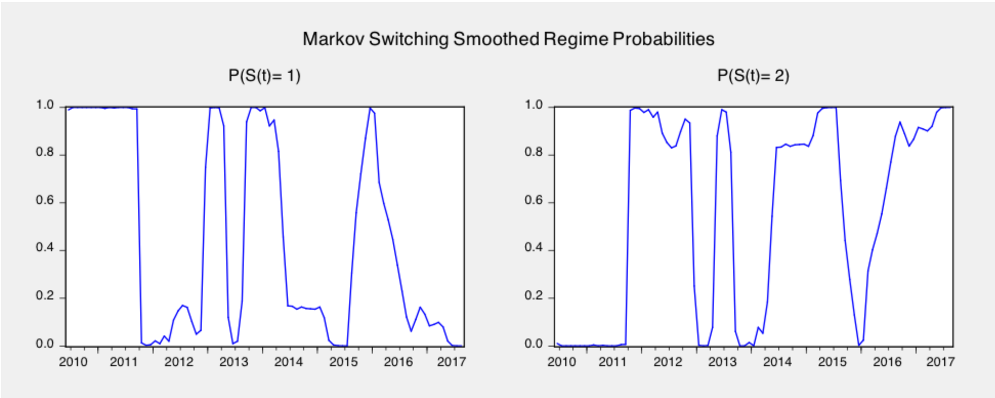

Figure 11: Regime probabilities by intervention regimes: 1 year NDF (reaction function)

D. Currency basket

In the main text we consider the RMB/USD exchange rate. The U.S. dollar is the most important currency from the trade and financial perspective. The anchoring currency of China's exchange rate policy is still the U.S. dollar as argued in Ilzetzki et al. (2019). While it makes a lot of sense to focus on the RMB/USD exchange rate, it is also important and interesting to look at the basket of currencies that RMB is pegged to. As officially announced in PBC's statement, it will try to stabilized the RMB exchange rate against a basket of currencies. Therefore, in this section we calculate the band of the RMB exchange rate to the basket of currencies.

The calculation is as follows: since the weight of China's currency basket is opaque, we need to estimate the weights. Following Frankel and Wei (2007) and Frankel and Xie

Currency	USD	EUR	JPY	KRW
Period 1: 2009.06-2010.06				
weights	0.989	0.011	0	0
Period 2: 2010.07-2015.07				
weights	0.923	0.056	0.008	0.013
Period 3: 2015.08-2017.08				
weights	0.792	0.099	0.063	0.036

Table 12: Weights for currency basket

(2010) we estimate the weight of the currency basket, which includes U.S. dollar (USD), euro (EUR), Japanese yen (JPY), and Korean won (KRW), using the following equation:

$$dlog(CNY) = \alpha_1 dlog(USD) + \alpha_2 dlog(EUR) + \alpha_3 dlog(JPY) + \alpha_4 dlog(KRW) \tag{19}$$

where we regress the log return of the RMB exchange rate on the four currencies and α_j coefficients capture the de facto weights on the constituent currencies. For the numeraire, we use the IMF's Special Drawing Rights (SDR). We focus on the sample period from 2009 to 2017. Based on the institutional background, we divide the whole sample into three sub-periods: Period 1 is from June 2009 to June 2010 when the RMB was strictly pegged to the USD; Period 2 is from July 2010 to July 2015 when PBC switched to a managed floating and enhanced the RMB exchange rate flexibility; Period 3 is from August 2015 to August 2017 when PBC further improved the RMB flexibility and maintained the stability of the RMB to the currency basket. We get different weights in different sub-periods which is summarized in Table 12. In Period 1, the USD accounted for 99% of the weight while in Period 2 its weight slightly dropped to 92.3%. After August 2015, the U.S. dollar accounted for 79.2% while Euro gained a share of 9.9%.

	(1)	(2)
Regime 1 vs. Regime 3		
$e - e_{trend}$	-90.30***	-109.26***
	(22.87)	(27.52)
$e_t - e_{t-1}$		47.73
		(31.84)
constant	-1.18***	-1.25***
	(0.32)	(0.34)
Regime 2 vs. Regime 3		
$e - e_{trend}$	77.31***	70.68***
	(20.04)	(20.81)
$e_t - e_{t-1}$		38.56
		(35.53)
constant	-2.56***	-2.58***
	(0.55)	(0.56)
N	87.00	87.00

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 13: Multinominal probit estimation (reaction function): Currency Basket