The anatomy of a peg: lessons from China's parallel currencies*

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Abstract

Two currencies circulate in parallel in China, the mainland CNY and the offshore CNH. This paper shows that, by coupling these dual currencies with capital controls, the monetary authorities can manage the peg between them to implement a wedge between domestic and foreign returns. This allows China to both internationalize the RMB, while steering its exchange rate with the USD and managing the current account. Using a rare instance of an exogenous transitory increases in the supply of money, we find causal evidence that they depreciate the exchange rate, and using an instrument for shocks to the demand for money, we find that the scarcity of liquidity and the exchange rate move hand in hand. We quantitatively decompose the relative contributions of monetary and liquidity policies in managing the peg. along the way, we find strong evidence for the pillars of monetarism.

JEL codes: F31, F33, E51, G15.

Keywords: Gresham's law, Goodhart's law, Money markets, Chinese monetary policy

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1 Introduction

For more than a decade, Chinese authorities have conducted a large-scale monetary experiment. Their challenge was to reconcile an open current account with a closed capital account. The former involves free trade of goods over multiple destinations by the world's largest exporter and its second largest economy. It requires a large volume of diverse payments across borders to settle trade invoices. The latter imposes tight restrictions on foreign investment and on payments associated with financial flows. It tires to achieve State control over the nation's net foreign assets. The former provides a strong force for the yuan to be used internationally; the latter restricts the yuan to be a domestic currency.

The Chinese answer was to create an offshore currency, the Hong Kong yuan (CNH), that circulates in parallel with the onshore currency, the mainland yuan (CNY). The CNH is freely used for payments and investments by anyone offshore, with no limits in converting it for foreign currency, while restricting the conversion into CNY to happen only against trade invoices. By the end of 2023, there were ¥2 trillion worth in transactions per day in CNH across the world fuelling 14% of global trade. The CNY, instead, is used onshore for all domestic transactions and it is required to directly invest in the mainland. Chinese nationals and firms wanting to invest abroad also face limits in converting it to CNH. By monitoring the conversions between CNH and CNY, the Chinese authorities can track financial flows, limit gross flows, and ensure that the assets held by Chinese abroad and by foreigners mainland are limited to specific categories.

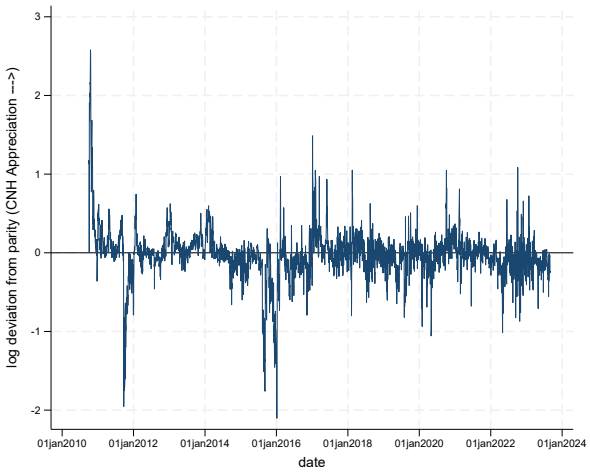
This monetary system has the tension that is common in parallel currencies. If one of the currencies were to persistently lose value relative to the other, Chinese firms, banks and households would want to convert it into the more valuable one. The capital controls that stop them from doing so would come under severe strain, and one of the currencies would sooner or later stop being used. This is Gresham's law. Yet, as figure 1 shows, even though the value of the yuan has fluctuated widely against the US dollar (USD), the exchange rate between its two variants has been very close to one.

This paper studies this system and its associated peg in four parts. First, we characterise how the People's Bank of China (PBoC) and the Hong Kong Monetary Authority (HKMA) have jointly managed monetary and liquidity policies. We show that complicated arrangements and institutions reduce to conventional monetary principles of keeping offshore liquidity scarce to steer the onshore-offshore exchange rate.

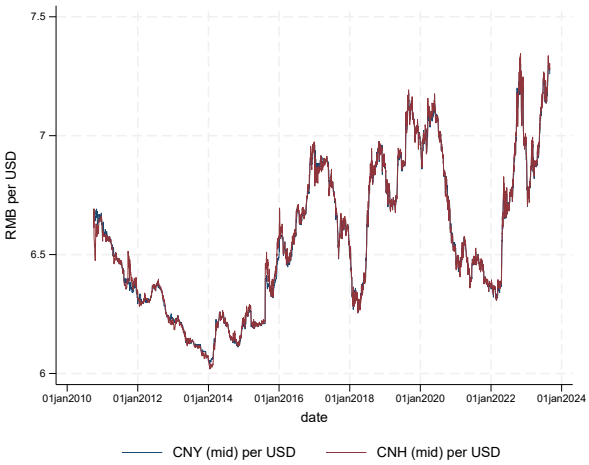
Second, we show in theory how the combination of scarce offshore liquidity with cap-

Figure 1: The relative value of the yuan

(a) Exchange rate of CNY with CNH



(b) Exchange rate of CNY or CNH with USD



Note: Sample period is all trading days between 1 October 2010 and 31 August 2023. In both panels, an increase is a yuan depreciation, either CNY relative to CNH or USD, or CNH relative to USD.

ital controls creates a wedge between domestic and foreign currency returns. It is well know that by controlling this wedge, policy has a way to affect the foreign exchange rate and the current account. Novel to this paper, we show that letting the onshore-offshore exchange rate deviate from parity temporarily is a way to implement a desired wedge. In turn, monetary and liquidity policies can be used to keep offshore liquidity scarce, and so eventually manage the foreign exchange rate.

Third, we use the Chinese experience to test the link between money and exchange rates. Its peculiarities provide a rare opportunity to credibly identify classical channels and to validate them with data on money, interest rates, and exchange rates. We find that exogenous increases in the supply of offshore yuan depreciate the offshore yuan relative to its onshore counterpart, while appreciating the onshore yuan relative to the US dollar. We estimate the elasticity of money demand, finding that the demand for reserves is much more elastic than the demand for deposits.

Fourth, we provide an anatomy of the peg into its monetary and liquidity components. Using an instrument for shocks to offshore money demand we find strong evidence that the authorities expand the money supply whenever the exchange rate appreciates in order to restore the peg. However, this only accounts for one sixth of the reversal of deviations from the peg, with the remainder achieved by liquidity policies. To investigate how they work, we write a model of the benefits of liquidity when the supply of money

is scarce, and find evidence for their channels using data on interbank rates, usage of liquidity facilities, bill auctions, and the 2015-16 crisis.

We conclude by discussing how our findings strongly support the key pillars of monetarism and by conjecturing what this implies for the rise of the yuan as an international currency.

Outline, contributions, and links to the literature.

Section 2 describes the policies conducted by the PBoC and the HKMA that: constrain CNY-CNH exchanges, keep the CNH money supply scarce on average, elastically adjust it to absorb shocks, and co-exist with policies on the exchange rate with the USD.[1] We show that, in spite of its peculiarities, the CNH monetary system is ultimately about using policies that affect the supply of money and the demand for liquidity to peg an exchange rate. The mechanisms that at first sight are opaque and complicated, after inspection reduce to standard channels used by central banks around the world.[2]

This section contributes to our understanding of monetary regimes, international currencies, and capital controls. The Chinese experience is interesting in its own right given the relevance of its economy in the international financial system.[3] Also, as the creation of the parallel currencies was a step towards internationalising the yuan, this experience carries lessons for understanding why some currencies are used in international trade.[4] Other countries may find this successful experiment with capital controls appealing in the future, and this paper explains how it has worked.

Section 3 turns to theory to explain the macroeconomic implications of this mix of capital controls and an offshore currency. We start from a canonical intertemporal model of the current account where a subsidy on capital flow creates a wedge in the uncovered interest parity (UIP) condition. This wedge in turn is linked one-to-one with the exchange rate of the country vis-a-vis foreign currency, and with current account balance and the net foreign asset position of the country. We then write a model that mimics the key

[1]The two central banks independently conduct monetary policy for two other currencies, the CNY and the Hong Kong dollar (HKD), which are not our focus. On CNY monetary policy, see Chen, Ren and Zha (2018), and on the HKD, see Genberg and Hui (2011).

[2]By creating an official parallel money market with policy-managed arbitrage trades, authorities may have prevented the rise of a private offshore market, like the Eurodollar (He and McCauley, 2012).

[3]In 1864, the US accidentally had a similar experience, as the civil war created parallel currencies with an exchange rate driven by the relative supply of money (Burdekin and Weidenmier, 2001).

[4]Naef et al. (2022) describe the components of this internationalisation, including CNH, and Bordo, Monnet and Naef (2019) compare the role of the offshore Hong Kong market with the London gold market during the internationalisation of the USD. We provide a more detailed description of the monetary and liquidity channels and policies of the offshore system.

features of the Chinese arrangement, with strict capital controls and offshore deposits that can be freely held both by domestics and foreigners. We prove that any equilibrium with a positive wedge can be implemented with a combination of monetary and liquidity policies. Furthermore, these are linked to the equilibrium onshore-offshore exchange rate. Therefore, using standard monetary tools, the authorities can have the onshore-offshore exchange rate temporarily deviate from the peg in order to affect the foreign exchange rate and the country's current account.

Segmenting markets to study exchange rates has a long tradition, but onshore and offshore markets motivate a different set of assumptions behind that segmentation (Alvarez, Atkeson and Kehoe, 2002). A modern literature equates the UIP wedge with capital controls and assume that these are a policy tool (Bianchi and Lorenzoni, 2022). Our model clarifies that constraints on where different agents can and cannot invest, paired with an offshore market, indeed creates a wedge that policymakers can target.

Section 4 tests the key monetarist force in terms of the classic question: by how much does a 1% increase in the domestic money supply depreciate the exchange rate? At one theoretical extreme, the quantity theory states that the exchange rate would depreciate by 1%, and the experience of hyper-inflations provides some support. At the other extreme, when policy chooses the interest rate on reserves and the demand for liquidity has been satiated, then the effect would be zero, as arguably has been the case in advanced economies after quantitative easing with ample reserves. Empirically, showing a causal link is challenging because money is endogenous, exchange rates move in anticipation of fundamentals, and there are many omitted variables that affect both.[5] The Chinese experiment with a peg provides a laboratory to isolate the channels linking monetary policy and exchange rates

We exploit changes in the timing of CNH monetary operations between 2019 and 2021 that caused nine expansions in the offshore money supply that were exogenous, moderate in size (1.5% of deposits on average), and transitory (lasting a few weeks). Relative to the literature, we follow in the tradition of the narrative identification of shocks to the supply of money.[6] We find that the onshore-offshore exchange rate depreciated on aver-

[5]Meese and Rogoff (1983) found no correlation between measures of money and exchange rates. Progress has come from finding that measures of liquidity affect deviations from UIP (Engel and Wu, 2023), that foreign exchange interventions are effective (Bordo, Humpage and Schwartz, 2015), that quantitative easing announcements move the exchange rate (Dedola et al., 2021), and that the quantity of bonds in private hands affects their convenience yield (Jiang, Krishnamurthy and Lustig, 2021, Valchev, 2020, Gourinchas, Ray and Vayanos, 2022, Greenwood et al., 2023). We estimate directly how much an increase in the stock of money in exchange for short-term bills changes the exchange rate.

[6]Friedman and Schwartz (2008) is the classic reference. The closest studies are Velde (2009) that identifies

age by 0.11 percentage points during these events While the literature has struggled to tightly estimate the interest elasticity of money demand, our model shows that there are two relevant elasticities: the elasticity of demand for reserves at the central bank and the elasticity of demand for bank deposits. We estimate that the former is approximately five times larger than the latter.[7]

We further find that the offshore-foreign exchange rate depreciates following an increase in the money supply. This confirms a key channel in the theory. In practice, a negative co-movement between the CNY-CNH and the CNY-USD exchange rates implies that the offshore market is an escape valve that smooths changes in the exchange rate of the yuan with the dollar. We contribute to the literature on foreign exchange interventions by unveiling the use of offshore currencies as an effective tool.[8]

Having described the institutions behind this successful peg, and understood and estimated the monetary channels that sustain it, section 5 provides an anatomy of the peg. We start by estimating the policy rule for the money supply. The features of CNY-CNH-USD again suggest a novel identification strategy. We show that movements in the CNY-CNH exchange rate proxy for changes in the demand for CNH money, and that the PBoC's management of the CNY-USD exchange rate produces an instrument for these demand shocks. We find that, following an increase in demand for CNH money that raise the onshore-offshore exchange rate by 1%, the daily supply of CNH money increases by 2.6% over the next 5 days to help restore the peg. This gives a monetary anatomy of this particularly successful peg.[9] This estimated policy rule for money falls short of fully bringing the exchange rate back to parity. We estimate that 5/6ths of the adjustment happens through liquidity policies.

Section 6 lays out what those policies are in theory, and estimates their effectiveness in the Chinese context. It starts from an existing micro-founded model of the marginal ben-

three large contractions in the money supply in France in 1724, and Palma (2021) that uses major discoveries of precious metals in America raising the money supply in Europe. We complement this work by studying a recent experience with a modern central bank, and by identifying high-frequency shocks to reserves, as opposed to banknotes. Also, we estimate relevant elasticities within a model and the separate role of different monetary and liquidity policies.

[7]There is an enormous literature estimating the impact of monetary policy shocks to interest rates on exchange rates using time-series variation, e.g., Eichenbaum and Evans (1995). Differently, we use high-frequency narrative identification, within a peg, with policy set on the quantity of money, and in combination with other liquidity policies. Chodorow-Reich et al. (2019) is closer, by exploiting cross-regional variation during the Indian demonetization, but on banknotes as opposed to reserves.

[8]Jermann, Wei and Yue (2022) inspect comprehensively the way the PBoC manages the CNY-USD exchange rate, while we focus and go deeper on the use of the offshore-onshore currencies.

[9]Typical pegs do not last long, and parallel currencies usually end in collapse, see Selgin (2020).

efit of liquidity, extended it to the offshore context.[10] The liquidity policies in the model are: reserve requirements, the interest rate on the discount window, regulations affecting matching in interbank market, purchases and sales of bills by Chinese state banks akin to FX helicopter drops, and restrictions on liquidity flows of deposits and reserves within the offshore and onshore divisions of a bank.[11] They all affect bank's willingness to create deposits (inside money), providing a fresh take on a host of policies that affect the exchange rate.[12]

We test three predictions for the impact of our identified shocks to money demand on: money-market variables like interest rates, demand for bonds, and central bank lending.The evidence supports all three, which shows hos financial innovation by banks will put pressure on the peg to break.[13] We further show that these tools have been used by the Chinese authorities, and discuss the extreme events of 2015-16 and how they confirm the predictions of the model.[14]

Finally, section 7 concludes by linking our results to the basic principles of monetarism dating back to the old Chicago School in their modern statement: Friedman and Schwartz's dictum that increases in the money supply lower the value of the currency; the Mussa and Frenkel policy prescription that systematically increasing the money supply when the exchange rate appreciated is the way to keep a peg; Goodhart's law that it is not enough to control the money supply, but one needs liquidity policies to offset shocks to money demand to keep inflation stable; and Gresham's law that parallel currencies can only survive if deviations from parity are temporary and short lived. More speculatively, our results tentatively suggest that a coherent monetary and liquidity framework can maintain a peg, keep the parallel onshore-offshore currencies, and provide new tools to affect the exchange rate with foreign currencies.

[10] We use the formulation of Poole (1968) by Bianchi and Bigio (2022) and Bianchi, Bigio and Engel (2021).

[11] Combining our estimates of liquidity benefits with the models of Engel (2016) and Engel and Wu (2023), which link them to convenience yields, would link monetary and liquidity policies to output or inflation.

[12] A complementary literature studies the role of capital controls and regulations on credit, capital allocation, and financial stability (Hachem and Song, 2023, Song and Xiong, 2018, He and Wei, 2023).

[13] We focus on financial innovation in the flow of liquidity; for the liberalization of bond and stock holdings, see Clayton et al. (2023) and He, Wang and Zhu (2023), respectively.

[14] Monnet (2014) uses time-series variation to identify the joint impact of a menu of liquidity policies on aggregate variables in France in 1948–73. We instead use high-frequency data and a model of each policy to provide an anatomy of the channels through which each of them affects the exchange rate.

2 The offshore market and the CNH monetary regime

There is a single physical currency in China—the renminbi (RMB)—but there are two separate digital currencies for bank deposits and for making electronic payments: the CNY used onshore in mainland China, and the CNH used offshore in international financial centres like Hong Kong.[15] A Chinese citizen or firm that deposits RMB banknotes into a bank in Shenzhen has a claim in CNY; a bank deposit a few miles away in Hong Kong is a claim in CNH. They are settled through separate real time gross settlement (RTGS) systems, have different interbank markets in which banks lend CNH or CNY to each other, and distinct retail markets where firms can borrow either currency from banks. Onshore CNY exchanges for offshore CNH, subject to restrictions, at a market exchange rate of E. This section describes these restrictions and the policies that support it.

2.1 Capital controls and restrictions on exchanging CNY and CNH

Only banks domiciled in China can supply CNY deposits and have access to the onshore China National Advanced Payment System to settle payments with reserve accounts at the PBoC. Only Chinese nationals can hold and use CNY deposits, with only a few exceptions for foreigners authorised by the government. Since CNY is required to buy and sell assets in mainland China, or more generally to transact in the onshore financial market, the limits in accessing CNY create a control over capital inflows.

The CNH can be held by anyone. It was first introduced to businesses in 2004, but only officially launched in July of 2010 as part of a package of financial reforms to create an offshore market, lower trade credit costs, and jumpstart the international use of the yuan.[16] Foreigners can hold deposits in CNH at will, make payments in CNH without restrictions, and convert CNH into foreign currency with no limits. Both Chinese and foreign banks with offshore branches or subsidiaries can issue CNH deposits. International financial centres settle transactions in CNH without constraints, and provide convertible deposit balances and trade credit without limits. Chinese firms that sell products or buy inputs from abroad can use CNH to make payments or to exchange it for another medium of payment, without any restrictions on quantity or composition. In short, access and use of the CNH is free, which has allowed the yuan to be used abroad and has contributed to

[15] Three quarters of offshore RMB transactions occur in Hong Kong, with London, Singapore and Taiwan being the other notable offshore centres. We restrict ourselves to data from the Hong Kong centre, leaving for future work a comparison with the other offshore centres.

[16] See Bahaj and Reis (2020) on the jumpstart, and, more recently Chupilkin et al. (2023) on its recent rise.

making China the largest exporter in the world.

Two Chinese economic agents that have accounts in both the mainland and Hong Kong and want to pay each other, can do so using their bank balances in either CNH or CNY. However, to invest abroad, Chinese citizens must exchange their CNY for another currency. Therefore, limits in accessing CNH create a control over capital outflows.

Official conversion of CNH for CNY, and vice versa, is one-to-one but is subject to many strict exchange limits. First, for purposes of investment, there are quotas on exchanging CNH and CNY whether into China using the CNY (through the Renminbi Qualified Foreign Institutional Investor program) or out of China using the CNH (through the Qualified Domestic Institutional Investor program). Restrictions also apply to firms trying to export or import capital.

Second, for consumption, households have an annual limit on how much they can transfer between CNH and CNY and vice versa. Shipping large quantities of RMB cash into and out of mainland China is forbidden.

Third, the Chinese firms that import or export using CNH or foreign currency can convert their CNH revenues to pay their CNY bills in mainland China only when they present the invoice behind their foreign sales (vice versa, they can convert CNY to CNH with an invoice for a purchase). These are the largest flows between CNH and CNY and their restrictions have led to large Chinese trading firms building up CNH deposits and associated invoices. They can earn CNH deposit rates or save in CNH bills, before converting these to CNY when there is an arbitrage opportunity.[17]

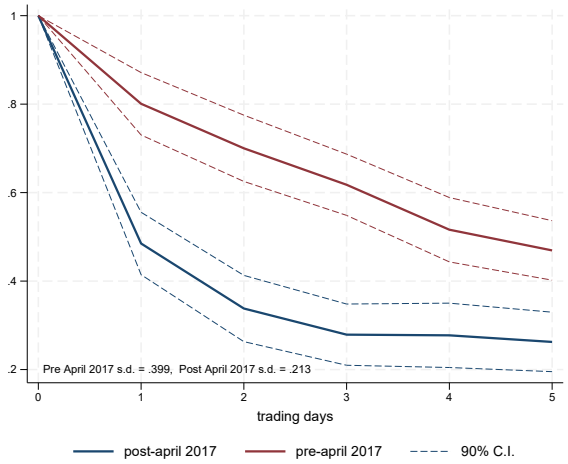
The other active arbitrageurs between CNH and CNY are the Chinese banks that have a presence offshore. They can borrow and lend in either CNY or CNH, as well as issue deposits in either, so in principle they can arbitrage differences in returns. The fourth set of restrictions is on these cross-border interbank lending

All combined, since most capital flows can be thought of as ultimately exchanging CNY for CNH, by limiting this exchange, Chinese authorities can effectively enforce controls on the flow of capital in and out of mainland China. At the same time, if the exchange rate between the two currencies is not one, or if expected returns in financial investments in either are different, then there is scope for arbitrage, which can be undertaken mainly by firms and banks.

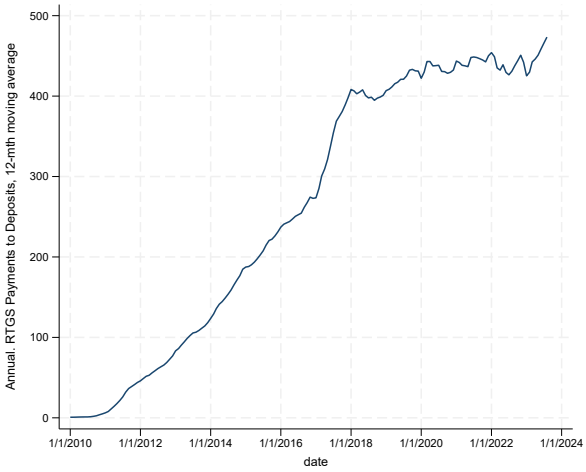
[17] Hu and Yuan (2021) and Liu, Sheng and Wang (2022) study firms exploiting the arbitrage opportunities.

Figure 2: The impact of the 2017 reforms

(a) Auto-correlograms of $\log(E)$ pre/post 2017



(b) CNH velocity



Note: Panel (a) compares the daily autocorrelograms in $\log(E_t)$ between October 2010 and March 2017 in red, and between April 2017 and May 2023 in blue. Panel (b) shows the ratio of annualized payments from the RTGS system to the stock of CNH deposits.

2.2 The survival of parallel currencies and the peg to parity

The limits to converting CNH and CNY constrain the arbitrage and allow for deviations from parity. However, if these deviations were large and persistent, then the profits from evading the capital controls would be large. Chinese firms, banks, and even households would make payments with the cheaper currency and hoard the more valuable one. Eventually, the capital controls would fail, and either arbitrage would bring about parity, or one of the currencies would disappear from circulation.

This imposes a necessary target for policy to keep the deviations of the CNY-CNH exchange rate from parity small and transitory. CNH monetary policy is subordinated to this goal. Figure 1 already showed its success over more than a decade: the daily standard deviation of $\log(E)$ was a mere 0.32% and only in a handful of days did it exceed 1%.[18] At the same time, the transaction costs on the arbitrage trade of converting CNY to CNH via USD were on average about 0.04% over the sample. That deviations from parity regularly exceed this number is evidence that the capital controls bind.

There was a structural break in the success of the peg in 2015–17. In August 2015, there was a reform in how the PBoC manages the exchange rate with the USD, which

[18] Appendix **??** lists all data sources and variable definitions.

triggered a new framework for managing the CNH that was set up in 2016–17. The left panel of Figure 2 shows the improvement in maintaining the peg: the standard deviation of the exchange rate fell by half and the half-life of deviations went from 6 days to 1 day.[19] The right panel shows the velocity of CNH money, by dividing all CNH RTGS transactions in Hong Kong in one year by the average stock of CNH deposits. The 2015–2017 reforms significantly increased this velocity, which averaged 431 between 2018 and 2022. By comparison, the average velocity for the United States, equivalently defined as the annual ratio between Fedwire transactions and M1 less currency, was 450 on average between 2012 and 2019.

Because of this break, from now onwards, we discuss the post 2017 system and all the empirical tests that follow are for the sample from April 1st of 2017 until August 31st of 2023. Section 6 will discuss and analyse events in the 2015–17 period.[20]

2.3 The CNH monetary framework

To fix ideas, panel (a) of table 1 plots the conventional balance sheets of a hypothetical central bank and commercial banks in an advanced economy. Central banks routinely increase the money supply through three conventional operations.

The first is an open market operation: buying government bonds from banks in exchange for increasing the balance in their reserve accounts. This can be structured as a direct sale, or as a repurchase agreement, where the two parties agree to unwind the operation in future. Either way, items (A) and (D) would increase in the central bank's balance sheet, and item (I) rises while (G) falls in the banks' balance sheet. The second operation is the redemption of central bank bills at term, item (E), in exchange for reserves, item (D). The corresponding items for banks are (H) and (I). Since reserves, as a settlement asset, are more liquid than bonds or bills, both of these operations expand liquidity. The third operation works through lending facilities to banks, which raise items (B) and (D) in the central bank's balance sheet, and items (I) and (L) in the banks' balance sheet. Note that all three variants lead to a rise in item (I), the holdings of reserves by banks, for short the money supply. This may change the willingness of banks to make loans, item (J), and the interest they pay on deposits so that the private supply of money (K) rises further.

The supply of CNH money has two extra arms involved, displayed in panel (b) of table

[19] Figure **??** in appendix **??** shows the autocorrelation function every thirty minutes. It declines moderately, and this is reversed at the end of the day, justifying a focus on a daily frequency.

[20] For descriptions of the pre-reform and reform periods, see Funke et al. (2015), McCauley and Shu (2018).

Table 1: Monetary policy operations

Panel (a) The conventional case

Central Bank

Assets	Liabilities
(A) Government Bonds	(D) Reserves
(B) Lending Facilities	(E) Bills
(C) FX and Other Assets	(F) Equity, Others

Commercial Banking System

Assets	Liabilities
(G) Government Bonds	(K) Deposits
(H) Central Bank Bills	(L) CB Facilities
(I) Reserves	(M) Equity, Others
(J) Loans, Others	

Panel (b) The CNH operations

People's Bank of China

Assets	Liabilities
(a) CNY Assets	(c) CNY Onshore Reserves
(b) FX Assets	(d) CNY Clearing Bank Reserves
	(e) CNH Bills
	(f) Equity, Others

Offshore Clearing Banks

Assets	Liabilities
(g) CNY Clearing Bank Reserves	(i) CNH Commercial Bank Sight Deposits
(h) Other Assets	(j) CNH HKMA Deposits
	(k) CNY Equity, Others

Hong Kong Monetary Authority CNH

Assets	Liabilities
(l) Deposits at Clearing Banks	(p) Equity, Others
(m) PLP Balances	
(n) Liquidity Facilities	
(o) Other Assets	

Hong Kong Commercial Banks CNH

Assets	Liabilities
(q) Deposits at Clearing Banks	(t) Deposits
	(u) PLP Balances
(r) PBoC CNH Bills	(v) HKMA Facilities
(s) Loans, Others	(w) Equity, Others

1. The first of these is the offshore clearing banks. They are private entities, although they are all subsidiaries of large state-owned banks in China, and their activities are closely regulated by the PBoC. They hold reserves onshore at the PBoC that are denominated in CNY, but they issue sight CNH deposits that are effectively the CNH reserves held by offshore commercial banks.[21] Each clearing bank operates its own RTGS system (which is then linked to the clearing banks' accounts at the PBoC and the onshore China National Advanced Payment System) and settlement of transactions offshore happens when a correspondent bank exchanges a CNH sight deposit at a clearing bank, just as in a typical payment system. When a firm or household converts a unit of CNH to CNY in order to make a payment onshore, then lines (q) and (t) fall at their commercial bank, which triggers a fall in lines (g) and (i) at the clearing bank and a fall in line (d) and increase in line (c) at the PBoC.[22]

[21]The offshore clearing banks also handle the offshore issuance of RMB banknotes.

[22]Banks domiciled in China can also access the Cross-border Interbank Payment System (CIPS) settlement accounts to make cross-border payments for approved reasons or to act as agents for foreign banks.

This separation means that CNH is only present in the PBoC's balance sheet through the small amount of bills in line (e). Therefore, movements in the CNY-CNH exchange rate have little impact on the unconsolidated PBoC balance sheet, but create (so far small) capital gains and losses for the clearing banks. This separation may be fiscally relevant if the peg is ever abandoned. But, integrating the two balance sheets makes little difference for the PBoC's influence over the money supply.

The second new arm is the HKMA. In order to preserve financial stability in Hong Kong, the HKMA is also committed to the peg, together with liquidity regulations over these banks. It holds CNH balances at the clearing banks, and lends to the offshore commercial banks through two distinct programs. The first is a repurchase agreement, with up to ¥18bn available, that is open to nine select banks in Hong Kong, the primary liquidity providers (PLP), which are responsible for channelling liquidity to the CNH interbank and financial markets. When they borrow from the HKMA, they automatically increase the supply of reserves in circulation. The outstanding PLP volume averages about ¥3bn during the sample period, which is approximately 1/25th of the volume of CNH bills outstanding, with much variation day to day (see figure **??** in appendix **??**).[23]

The other programs are repo facilities that supply CNH liquidity immediately, one intraday and one overnight. They are open on demand to all banks operating in Hong Kong that are willing to pay a penalty spread over the interbank rate. Unlike typical discount windows, these are used very heavily (daily, by several banks) and much more than the HKMA's discount window for Hong Kong dollars (which was used only 11 times in 2021). Because intraday funds can frictionlessly convert to an overnight loan, Hong Kong banks prefer to use the intraday facility, as it retains the option to repay the loan early. As a result, while the intraday facility is heavily used every day, the overnight one has balances close to zero most days (see figure **??** in appendix **??**).

Again, the fiscal risk, in this case from default by the banks that borrow CNH, does not lie with the PBoC. Again, outside of a financial crisis, integrating the two authorities' balance sheets makes little difference for the joint control of the money supply.

In short, while its institutions and operations are peculiar, the CNH monetary frame-

The CIPS reserves are separate from the PBoC reserves, they are remunerated differently, and are subject to different liquidity policies. They are an alternative offshore clearing bank with a volume of cleared transactions that is an order of magnitude lower than the CNH-CNY flow.

[23]Left out of the table is a permanent swap line between the HKMA and the PBoC. If the demand by banks of the HKMA's programs exceeds the HKMA's balances at the clearing banks, it can borrow CNH as needed to prevent a liquidity crisis. As of July 2022, the HKMA's swap line limit was ¥800bn, about the same as the total stock of CNH deposits in Hong Kong.

work can be unpacked into standard conventional monetary and liquidity mechanisms.

How large is the money supply? The average stock of CNH deposits in Hong Kong banks between January of 2018 and August of 2023 was ¥730bn. We do not have an accurate measure of CNH reserves, but we know that bank deposits at the clearing banks were on average ¥311bn, of which ¥80bn are absorbed by the stock of PBoC bills, and that the HKMA has a balance of at most ¥35bn.[24] This gives an estimate of reserves held by banks of ¥196bn. This would imply a money multiplier of 3.7. By comparison, the ratio of M1 without currency to reserves in the United States was 13.3 over 2004–06 (when money was scarce) and 1.6 over 2021–23 (when reserves were ample).

2.4 How are CNH monetary and liquidity policies conducted?

The CNY-CNH peg is not enforced by law or regulation, but by deliberate policy actions that keep $E' = 1$, where E' is the exchange rate next period.

Monetary policy in CNH does not involve setting interest rates. The interest rate on the CNH sight deposits at the clearing banks is zero. The interest rates on the PLP balances and the liquidity facilities are endogenous, indexed to market interbank rates. Because the supply of CNH money is scarce, these interbank rates are well above zero.

Monetary policies. Open market operations in CNH are not appropriate as there is a limited stock of CNH government bonds. Instead the PBoC has issued a stock of short-term bills, with maturities of 3, 6 and 12 months, and conducts auctions of new ones at pre-announced dates that follow a regular schedule. Those auctions typically coincide with previous bills maturing to keep the money supply smooth, subject to the changes in the quantity of money targeted by the PBoC. Concretely, as the bills mature and are paid, the stock of money increases, while when they are issued, it falls. By controlling the quantities in these weekly/monthly auctions, targets the money supply of CNH reserves.

In terms of the balance sheets, a bill that rolls off causing an increase in money supply maps into a fall in line (e) and a rise in line (d) in the PBoC balance sheet, together with a rise in lines (g) and (i) in the clearing banks, and an increase in line (q) and fall in line (r) in the commercial banks (potentially followed by rises in (s) and (t) through private money creation). While there are more intermediate links in the chain, the net operation is a completely conventional repurchase operation of central bank bills.

[24] The HKMA's nine PLPs have a cap of ¥2bn each, while the two repo facilities have a cap of ¥10bn each, and the average amount outstanding in the PLPS was ¥3bn, giving: $2 \times 9 + 10 \times 2 - 3 = 35$bn.

The HKMA adjusts the money supply day-to-day through its PLP lending. Again this works just as in a conventional central bank lending facility: line (l) falls and (m) rises at the HKMA, and lines (q) and (u) rise at the commercial banks. While the weekly PBoC policies could change the money supply exogenously, the hourly actions of the HKMA endogenously supply money to absorb shocks to demand.

Liquidity policies. The PBoC regulates the clearing banks and the HKMA regulates the commercial banks. These rules (and suasion) impose restrictions on the endogenous creation of private CNH money by financial intermediaries.

First, both authorities impose minimum balance requirements on banks. These reserve requirements on CNH deposits change at low frequencies.

Second, the HKMA sets the interest rate on its discount window. Currently, it is priced as a spread to the CNH interbank market rates in the previous three days, so the cost for banks of having CNH shortfalls and needing emergency liquidity increases as existing liquidity becomes scarce.

Third, the PBoC places limits on the total flow of deposits and reserves between the onshore and the offshore interbank markets. These are heavy-handed policies since these flows vary widely every day depending on household and firms's liquidity needs.

Fourth and finally, the media reports that Chinese State banks buy and sell CNH at the encouragement of the authorities. Effectively, these are FX interventions, similar to helicopter drops of CNH reserves to buy CNY government bonds.

2.5 Policies regarding the CNY and the USD

Mainland monetary policy is set entirely by the PBoC. It involves traditional channels, setting interest rates and controlling the supply of money, with a focus on mainland variables and domestic goals. The CNY money supply is much larger than CNH's: roughly 200 times larger on average between 2018 and 2023.[25]

There is no evidence that the PBoC has, in our sample, changed onshore monetary policy in response to the small daily fluctuations in the CNY-CNH exchange rate. CNH monetary policy is solely focused on the peg, precisely so that CNY monetary policy can ignore E almost entirely. Regressing the stock of monies on the CNY-CNH exchange rate, there is a quantitatively and statistically significant correlation only with CNH money, but not CNY money (table **??** in appendix **??**.)

[25] Back to panel (b) in table 1, line (c) is much larger than the sum of lines (i) and (j).

The PBoC actively interferes instead in the CNY-USD exchange rate, call it $\tilde{E}$. It does so by setting a "central parity rate" at the start of the day, $\bar{E}$, and then intervening during the day so that the deviation $\log(\tilde{E}) - \log(\bar{E})$ does not exceed 2% in absolute value. This is a managed float that prevents large appreciations or depreciations within one day.[26] Jermann, Wei and Yue (2022) describe how the parity rate is set; importantly, for our purposes, the CNY-CNH exchange rate does not appear in their discussion, supporting an exclusion restriction that E does not enter the decision rule for $\bar{E}$, and so the latter can be used as an instrument for the former.

Most of the time, the parity rate adjusts to match the previous market rate and this trading band does not bind. Sometimes though, the PBoC does not adjust the central parity rate to market conditions fast enough, for example if the CNY is depreciating quickly and the PBoC wants to slow this down. At these times, the CNY-USD exchange rate binds at the bottom of the band, and there is unfulfilled pressure for the CNY to depreciate further. In anticipation of this, market participants would want to sell CNH today as no trading band exists in the offshore market. The CNH would trade below parity. In this sense, the CNY-CNH exchange rate mechanically acts as an escape valve for the appreciation and depreciation pressures over the CNY-USD.

Finally, and for completeness, the medium of exchange for transactions in Hong Kong is a separate currency, the Hong Kong dollar. The HKMA manages it independently of the CNH market, with a separate balance sheet, and a separate set of policies. The HKD is not subject to capital controls and is pegged to the USD via a currency board backed by the HKMA's substantial foreign exchange reserves, which are separate from China's own reserves. The HKD plays little role in understanding the CNY-CNH-USD setting.

3 A model of capital controls and offshore money

We start with a canonical model of an intertemporal current account and the UIP condition, which the government tries to manipulate via a capital flow tax. We then introduce a model of capital controls, where domestic private agents cannot invest abroad, and foreigners cannot invest in domestic assets. The exception is an offshore money market, where both can hold deposits issued by banks. This matches the CNH-CNY-USD application. Our main result is that by changing monetary and liquidity policies to make

[26] The 2% limit has been in place since March of 2014, when it was widened from a 1% limit set in April of 2012. Prior to August 2015, the parity rate was close to being a constant, but since then it has changed over time through a countercyclical factor and by considering a basket of currencies beyond the USD.

the onshore-offshore exchange rate deviate from parity, the government can mimic the outcomes with the capital flow tax.

3.1 A canonical model of a managed current account

The model. Consider a two-period world where a representative consumer in a small open economy with a given endowment has perfect foresight. Her preferences are:

$$u(c_{NT}, c_T) + \beta u(c'_{NT}, c'_T) \tag{1}$$

over non-tradeable (c_{NT}) and tradeable goods (c_T), with a discount factor parameter $\beta \in (0,1)$. The exchange rate $E^{\$}$ is the price of the tradeable good in units of the non-tradebale, which we take as the numeraire

The agent has an endowment in the first period (y_{NT}, y_T) and the second period (y'_{NT}, y'_T) and she can save in the domestic financial market and amount b^h, and in the foreign financial market $b^{\$}$. The respective returns of the two types of investment are $(R, R^{\$})$. Savings abroad are at the foreign exchange rate $E^{\$}$, which gives the prices of foreign savings in units of domestic non-tradeable goods.

The budget constraints therefore are:

$$E^{\$} c_T + c_{NT} + b^h + E^{\$} b^{\$} = E^{\$} y_T + y_{NT} \tag{2}$$

$$E^{\$\prime} c'_T + c'_{NT} = E^{\$\prime} y'_T + y'_{NT} + R b^h + (1+\tau) R^{\$} E^{\$\prime} b^{\$} - T' \tag{3}$$

Crucially, the agent pays a subsidy τ for saving abroad. This would be the case for a government that is trying to have the economy run a larger current surplus than without policy intervention. By subsidizing savings abroad, the policymaker incentivizes agents to consume less and instead export their tradeable output. The government rebates the proceeds of this subsidy back to the household in the last period, through the lump-sum transfers: $T' = \tau R^{\$} E^{\$\prime} b^{\$}$.

Markets clear when the consumption of non-tradeables equals their endowment, and the internal financial market clears: $b^h = 0$. As for the foreign assets, there are also foreign investors that could invest abroad earning the exogenous return $R^{\$}$, or domestically having to pay the equivalent tax at rate τ. Therefore, gross investment abroad $b^{\$}$ is not pinned down, but only net foreign assets: $B^{\$}$.

Equilibrium. It is standard to derive the equilibrium of this canonical intertemporal

model of the current account. We add three simplifications, which are irrelevant to the results, but simplify the algebra. First, we simplify the units of measurement by setting $y_{NT} = y'_{NT} = 1$, so that in equilibrium the return on domestic assets is constant: $R = \beta^{-1}$. Second, we use the functional form for the utility function: $u(c_{NT}, c_T) = \ln(c_{NT}) + \iota \ln(c_T)$, with parameter $\iota > 0$ so that the current account balance is given by the simple expression: $E^{\$} y_T - \iota$. Third, we assume that $(1+\tau)\beta y_T > y'_T / R^{\$}$ so that the country has positive net foreign assets $B^{\$} > 0$.

There are three key equilibrium conditions. The first follows from the optimal savings behavior of domestic abroad or, equivalently, from the absence of arbitrage opportunities for foreigners:

$$1 + \tau = \frac{E^{\$} R}{E^{\$\prime} R^{\$}} \tag{4}$$

This is the uncovered interest parity condition, equating the returns of the two investments once expressed in the same units. The subsidy drives a wedge between them, favoring foreign investments over domestic ones, and thus making them pay a lower return in equilibrium.

The second and third condition are the balance of payments conditions equating the current account balance to the net foreign asset position:

$$E^{\$} y_T - \iota = E^{\$} B^{\$} \quad \text{and} \quad \iota - E^{\$'} y'_T = R^{\$} E^{\$\prime} B^{\$} \tag{5}$$

Management of the exchange rate and the current account. Combining these three conditions gives the equilibrium value of the exchange rate:

$$E^{\$} = \frac{(1+\tau) R^{-1} + 1}{R^{\$-1} \frac{y'_T}{y_T} + 1} \frac{\iota}{y_T} \tag{6}$$

A higher subsidy τ raises the wedge between the two returns in the UIP condition in equation (4). Agents consume less, save more abroad, so the current account surplus rises. As they buy more foreign assets, the value of the foreign currency rises to adjust. Therefore, $E^{\$}$ increases with τ.

By controlling the subsidy τ, the government is able to manage its current account, or equivalently, its exchange rate. In this economy, it is sub-optimal to do so, although many elaborations of this canonical model feature externalities and financial frictions that make a non-zero τ desirable. In the data, we do not observe many instances of these capital

flow subsidies, so the literature has tended to refer to this wedge as capital controls or as macro-prudential policy. But how do such controls lead to wedge? The next section shows a monetary economy where this is the case.

3.2 A model of capital controls and offshore banking

Domestic households. Consider now the same world but where the representative household is forbidden by capital controls from investing abroad. That is, $b^{\$} = 0$. However, the household can now hold useful offshore money to make payments abroad. Her problem is now:

$$\max \quad u(c_{NT}, c_T) + \mu \ln(d^h) + \beta u(c'_{NT}, c'_T) \quad \text{s.t.} \tag{7}$$

$$E^{\$} c_T + c_{NT} + b^h + E d^h = E^{\$} y_T + y_{NT} \tag{8}$$

$$E^{\$\prime} c'_T + c'_{NT} = E^{\$\prime} y'_T + y'_{NT} + R b^h + R^d E' d^h + T' \tag{9}$$

where d^h are the deposits in units of offshore currency, E is the offshore currency exchange rate, R^d is the return on those deposits in offshore units, and μ is a demand preference parameter.

Optimal savings behavior still implies $R = \beta^{-1}$ but now there is a demand for offshore deposits by domestic households that trades off their utility benefits with their dominated return relative to onshore assets given by:

$$d^h = \mu \left(E - \frac{E' R^d}{R} \right)^{-1} \tag{10}$$

This demand function for money (deposits) has an interest semi-elasticity of $\varepsilon_d = R^d E' d^h / \mu E$.

Foreign investors. Foreigners likewise face capital controls. They cannot invest in the domestic assets. But, like households, they can hold offshore deposits in the amount d^f. The offshore money is therefore an international currency that private agents at home and abroad can freely hold.

The absence of arbitrage is now between foreign assets and offshore deposits. Thei

rreturns are equated once they are converted into the same units: [27]

$$E^{\$\prime} = \frac{E^{\$} R^{d}}{R^{\$}} \times \frac{E'}{E} \tag{11}$$

Offshore banks. A continuum of competitive offshore banks choose how many deposits (d) to offer to domestic and foreign investors, and use these proceeds to invest in onshore assets (b^l) and offshore reserves (m).[28] Like households, they also face capital controls and cannot invest abroad. Their problem is to:

$$\max \; Rb^l + E'R^m m - E' \left(R^d d + \phi(m/d, \lambda) d \right) \quad \text{s.t.} : \quad b^l + m = d \tag{12}$$

The bank incurs a liquidity cost per unit of deposit given by the function: $\phi(m/d, \lambda)$. These capture the problem facing the bank from offering liquid deposits to back illiquid domestic assets, in the sense that during the period there are random withdrawals of deposits that a bank must honor but cannot seel assets to do so. The bank must turn to borrowing from either other banks or the discount window, which is costly as captured by $\phi(.)$. Section XXX will write an explicit micro-foundation behind these costs.

We assume (and later micro-found) that the $\phi(.)$ function has four properties. First, it depends on the offshore reserve-deposit ratio m/d, so that marginal costs are constant with scale, and on liquidity policies, λ. We treat λ as a policy tool for now. Second, $\phi(.)$ is non-negative, reaching zero when the bank is narrow, $\phi(1, \lambda) = 0$, and is bounded above. Third the function is decreasing in the reserve-deposit ratio, since liquidity costs are lower when the bank's assets are more liquid relative to its liabilities. The marginal benefit $-\phi'(.) \equiv -\partial\phi(.)/\partial(m/d)$ is non-negative, reaches its minimum of zero when the bank is narrow, $\phi'(1, \lambda) = 0$, and is bounded above. Fourth, there are diminishing marginal benefits to holding more reserves: $\partial^2\phi(.)/\partial(m/d)^2 \leq 0$

Optimal behavior by banks. At an optimum, banks are indifferent between holding onshore assets of offshore reserves, so the following condition must hold:

$$\left(\frac{E'}{E} \right) \left(R^m - \phi'(m/d, \lambda) \right) = R. \tag{13}$$

[27] This demand for money by foreigners is, for simplicity, infinitely elastic. Appendix **??** extends the model to have an elastic supply of foreign deposits, mimicking that of domestic households.

[28] In the appendix we consider an extension where the bank can also take deposits and hold reserves onshore. This makes no material difference to the results. We abstract from the market power of banks or from financial repression suppressing deposits rates, so R^d clears a competitive market. It is not apparent to us how these would change the monetarist and liquidity conclusions here.

On the left-hand side are the expected returns from holding a marginal unit of offshore reserves. These include both the final return as well as the marginal reduction in liquidity costs. Inverting the cost function gives a money demand function stating how many reserves banks want to hold relative to deposits as a function of the opportunity cost of holding reserves, which depends on the interest rate spread and the exchange rate. The interest rate semi-elasticity of demand for reserves is $\varepsilon_m = (R^m d)/(m\phi''(m/d, \lambda))$ by the inverse function theorem.

The first-order condition from the banks' optimisation with respect to offshore deposits is:

$$R^d + \phi(m/d, \lambda) - \left(\frac{m}{d}\right)\phi'(m/d, \lambda) = \left(\frac{E}{E'}\right)R. \tag{14}$$

On the left-hand side is the cost of offshore deposits, which includes not just the interest paid to depositors but also the marginal increase in liquidity costs due to the extra deposit.

The government. The government comprises of a fiscal authority making transfers, an investment authority choosing how much to borrow domestically and how much to save abroad , and a monetary authority supplying a quantity of reserves. The government is the only domestic institution that can invest abroad. In many real-world cases of strict capital controls, private agents can invest abroad up to strict quantity limits, but the government is the marginal investor, which is the relevant feature of our model. Governments often impose capital controls precisely because they can keep track of where domestic savings go to, just as in the model.

In the first period, the government issues reserves (M), borrows in the domestic financial market (B^g) and invests abroad $B^\$$ subject to the budget constraint:

$$E^\$ B^\$ = B^g + EM \tag{15}$$

In the second period, the government collects or pays the returns from these investments and rebates the proceeds (or taxes the deficit) to the representative consumer:

$$T' = E^{\$'} R^\$ B^\$ + \phi(M/D, \lambda)D - RB^g - E'R^m M \tag{16}$$

We assume that the liquidity costs are not lots, but end up as revenue for the government. Later, this will follow from the micro-foundation where in equilibrium the government will earn these from operating the discount window.

Market clearing and policy rules. Using capitals to denote equilibrium values (or government choices), in the reserves market, $M = m$, while in the money market: $d = D = d^h + d^f$. In the domestic financial market, $B^g = b^h + b^l$, and in the market for non-tradeable goods: $c_{NT} = c'_{NT} = 1$.

Government policy consists of choosing monetary and liquidity policies (M, λ), together with desired assets held abroad $B^\$$. Note that the current account (or net foreign assets) of the economy is endogenous, and given by: $E^\$ B^\$ - Ed^f$. If the government chooses to hold more foreign assets, returns will adjust attracting or repelling foreign investors to the offshore market until markets clear.

Finally, the government credibly commits to delivering $E\prime = 1$. This is the constraint posed by Gresham's law. The onshore-offshore exchange rate can deviate from parity temporarily, but not persistently. Otherwise, the private sector would find a way to violate the capital controls.

Equilibrium. A key variable in the model is the aggregate reserve-deposit ratio in equilibrium. We denote it by $x \equiv M/D$. An equilibrium in the model is then an aggregate reserve deposit ratio, the offshore exchange rate, and the foreign exchange rate $x, E, E^\$$ that solves three equations.

The first equation comes from combining the market clearing condition for reserves with the demand for reserves from banks in equation (13) with the credible peg policy to get a UIP condition between onshore and offshore:

$$R^m - \phi'(x, \lambda) = RE \tag{17}$$

The second equation combines the market clearing condition for deposits, the demand for them in (14), the credible peg, and the balance of payments condition that results from market clearing and the household's budget constraint in (8):

$$\frac{\mu R}{\psi(x, \lambda)} = \frac{M}{x} - E^{-1}\left(E^\$(y_T - B^\$) - \iota\right) \tag{18}$$

where we have defined $\psi(x, \lambda) \equiv \phi(M/D, \lambda) - (M/D)\phi'(M/D, \lambda)$, the liquidity cost of issuing a deposit in equilibrium.

The third equation is the solution for th equilibrium exchange rate from combining the budget constraints and goods market clearing in equations (8)-(9), tothether with the

fiscal rule (**??**), and the UIP condition for foreigners (11) to arrive at:

$$E^{\$} = \frac{1 + \left(R - \frac{\psi(x,\lambda)}{E}\right)^{-1}}{1 + R^{\$-1}\frac{y_T'}{y_T}} \frac{\iota}{y_T} \tag{19}$$

Finally, recall that R^m, μ, y_T, ι and $R = \beta^{-1}$ are exogenous variables and that $M, \lambda, B^{\$}$ are exogenous policy variables.

3.3 An equivalence result

The appendix proves the following result:

Proposition 1. *There is a unique equilibrium for $x, E, E^{\$}$ that solves equations* (17)-(19) *as a function of policy $(M, \lambda, B^{\$})$. For any equilibrium exchange rate $E^{\$}$ of the canonical model with a wedge $\tau \in [0, \infty]$ that solves* (6)*, there is a choice of policy $(M, \lambda, B^{\$})$ in the model with capital controls that achieves the same equilibrium $E^{\$}$.*

Scarce offshore liquidity creates a wedge for households when choosing whether to invest domestically or in offshore deposits. Likewise, it creates a wedge between what foreigners can earn domestically instead of abroad. Combined, these pin down the onshore-offshore exchange rate. In turn, this affects the desirability of saving abroad, which pins down the current account, and therefore the foreign exchange rate

Comparing equations (6) and (19) shows that they differ because qith capital controls and offshore markets, there is a term $1/(R - \psi(.)/E)$ while with a capital flows tax there is an equivalent term $(1 + \tau)/R$. By using both M and λ, the policymaker can induce an equilibrium for the onshore-offshore exchange rate and for the liquidity cost of a deposit, that makes the first term match the same effects as that of nay subsidy τ.

Importantly, policy must keep the supply of offshore reserves scarce. If $\phi'(.) = 0$, so there were no liquidity benefits to money, then money is a pure financial asset and the banks' demand for it is horizontal (or $\varepsilon_m = \infty$). The supply of money would be irrelevant for the equilibrium exchange rate.[29] Equation (17) becomes $RE = R^m$ determining the exchange rate solely as a function of the gap between two exogenous rates. Policy could not longer control the UIP wedge.

[29]This is sometimes referred to as the cashless limit and has justified an ample reserves system where central banks using the size of their balance sheet and the interest they pay on reserves as independent policy tools.

Therefore, capital controls with an offshore market and scarce offshore money give policymakers the power to implement a UIP wedge that has been the focus of the literature on managing the current account.

4 Money and the exchange rate

The model's features matches the application to China's capital controls and offshore market. At its heart, it is a monetarist model, where controlling the quantity of M determines the exchange rate E, and form there the UIP wedge and current account. This section fleshes out that causal link, explains why the CNH-CNY-USD setup gives a laboratory to test this link, and uses the data to test it.

4.1 The impact of an increase in the money supply

Start by taking $E^{\$}$ as given. Then, the equilibrium for (E, x) is pinned down by the two equations (17)-(18). Figure XX shows these graphically, as the equilibrium relations in the reserve and the deposit markets, respectively.

An increase in the supply of offshore money M shifts the relation in equation (18). The deposit market equilibrium shifts up-left. The reserve-deposit ratio rises, and the offshore currency depreciates. Intuitively, more offshore reserves satisfy some of the banks' demand for liquidity. The liquidity premium on reserves is lower and banks require a higher return for holding them. The offshore exchange rate must be expected to appreciate, which for a credible peg implies that the current exchange rate must depreciate.

How much will depend on the slope of the reserve-market condition, and on how much the deposit-market condition shifts. The first depends on the elasticity of money demand by banks; the second on the elasticity of money demand by households.

In turn, equation (19) shows that E and $E^{\$}$ negatively co-move. By depreciating offshore money, savings shift abroad, and the foreign exchange rate appreciates.

Collecting all the results lead to the following proposition proven in Appendix **??**:

Proposition 2. *Following a transitory increase in the supply of offshore reserves M:*

a) The offshore currency depreciates in value relative to the onshore currency, E falls.

b) In the neighborhood of the peg ($E = 1$) and of where net foreign assets are approximately equal to official FX reserves ($E^{\$} y_T - \iota = B^{\$}$), the proportional change in the exchange

rate is a weighted sum of the two elasticities of money demand: $(d\log(E)/d\log(M))^{-1} = \varepsilon_m + x\varepsilon_d$.

c) *The offshore currency depreciates in value relative to the foreign currency,* $E^{\$}$ *rises.*

4.2 Testing the prediction

Why it is hard to test for monetarism. The monetary theory of exchange rates (Mussa, 1976) relies on downward-sloping demand curves for money but testing for a finite ε_m is hard for several reasons.[30]

First, most central banks most of the time set policy in terms of R^m, and have the supply of money accommodate demand. Therefore, there are few if any exogenous changes in the money supply M to conduct the test.

Second, even when they choose M, central banks follow policy rules that respond to the exchange rate E or to shocks that move D or shift $\phi'(.)$, creating a reverse causality. Moreovoer, large, persistent, and unexpected shocks to M will be correlated with changes in information and expectations of future policies and macroeconomic outcomes. There are signalling effects that may be unrelated to the liquidity services of money.

Third, the other currency's monetary policy also moves and responds to E. Moreover, shocks to equilibrium deposits D or to other factors determining the value of liquidity include changes in relative outputs and real exchange rates, or, in the more recent literature, changes in the risk appetite of financial intermediaries and in frictions to arbitrage. All of these omitted variables shows up in the model as changes in R, and are hard to control for.

The CNY-CNH testing ground. The CNH money supply M and the CNY-CNH exchange rate E provide a good setting to test for the causal impact of the money supply on the exchange rate because it overcomes the three empirical barriers.

First, the conduct of CNH monetary policy is to vary the quantity of CNH reserves supplied as opposed to the interest rate. In fact, $R^m = 1$ at all times in CNH reserves. There is hope to find exogenous changes in M.

Second, the monetary policy rule is known, adhered to, and successful: to keep parity, or $E' = 1$. Because the PBoC only adjusts its component of M at weekly (or less) frequency during the auctions of CNH bills, there is no reverse causality from high-frequency E to this component of M.

[30] A survey of the early literature testing it is in Boughton (1988), with new developments in Rogoff (1999).

Third, onshore CNY monetary variables, are chosen in response to onshore variables, as we explained in section 2. Therefore, onshore monetary factors affecting the exchange rate (which would shift R) do not respond to the shock M and so not cause ommited-variable bias. In fact, recall that CNH and CNY are designed to intermediate transactions in Chinese goods and services and Chinese agents have access to both. Therefore, there are few non-monetary movements in the real exchange that we must control for, especially at a high frequency. Therefore we can take R as given when it comes to determining E after an M shock. This would certainly not be the case with respect to onshore monetary policy.

4.3 An empirical test

The remaining challenge is to find changes in M that are exogenous and transitory.

Exogenous shocks to CNH money supply. The PBoC started issuing CNH bills in November 2018 on a schedule that would converge to a stock of ¥50bn of bills outstanding, with ¥40bn of 3-month bills and ¥10bn of 12-month bills. However, in the summer of of 2019, the PBoC altered the bill issuance schedule to increase the stock of bills to ¥80bn, with ¥20bn of 3 and 6-month bills, and ¥40bn of 12-month bills (alongside a temporary 1 month bill issued on 28th June 2019). On the 6th of November of 2020, the PBoC further announced it would lengthen the maturity structure by switching the composition to ¥10bn of 3 and 6-month bills and ¥60bn of 12-month bills while holding the stock fixed. By 2022 the stock converged to a level ¥80bn with any deviation closed within a very short window. The bill stock was expanded once again in August of 2023 to reach ¥110bn by the end of the year.

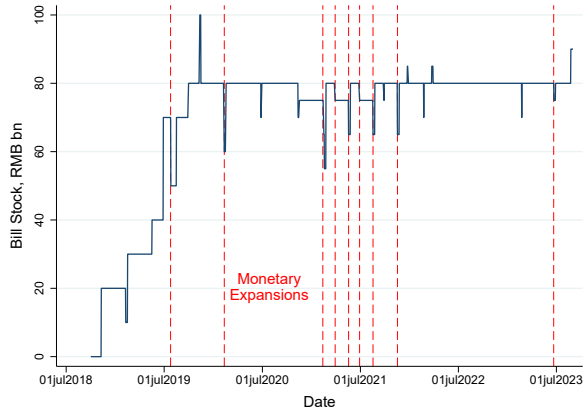
The two changes in the schedule of auctions in 2019 and 2020 were likely an endogenous policy response to the demand for CNH (as was, more evidently, the change in 2023). However, because they shifted the maturity structure, and since the auctions for different maturities are on a different schedule, they created future dates when certain bills exogenously rolled off without being replaced for at least 5 working days. In addition, the issuance of a 6-month bill in June 2023 was a few days later than usual which created an extra period where the bill stock was diminished.[31]

The left panel of figure 3 plots the outstanding daily stock of bills. As a result of the variation in the schedule, at the nine dates indicated by the vertical lines, old bills rolled

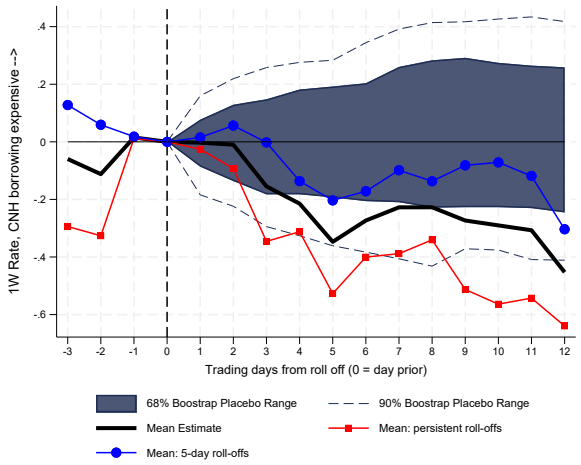
[31] This last event was partly due to an operational constraint having to do with the days of weekends in June of 2023. Our results are not sensitive to its inclusion.

Figure 3: Exogenous money supply shocks

(a) Money supply shocks through bill roll-offs



(b) Interbank rates around the expansions in money supply



Note: Panel (a) shows the stock of PBoC bills outstanding and its short-lived fluctuations caused by the shift in maturity structure in June/August 2019 and in November 2020. Panel (b) shows the CNH one-week interbank rate relative to the trading day prior to the bill roll off, averaged across the monetary expansion events. Also in the figure are bootstrapped placebo intervals from taking 10,000 random samples of an equivalent number of events dates between 1 July 2020 and 1 November 2021, excluding dates that overlap with the original event window and schedule announcements.

off without being immediately replaced by new bill issuances.[32] These events led to sharp and large declines in the stock of bills outstanding, of on average ¥11bn. Correspondingly, the CNH money supply expanded to redeem those bills at these dates. These monetary expansions were temporary. The previous supply of bills was re-established with the new issuance. In five of the roll-offs, the increase in money supply lasted 5 trading days, while in the other four the impact on money supply lasted on average for 25 trading days.

The right panel of figure 3 confirms that reserves were scarce: these expansions in money supply lowered the private opportunity cost of holding reserves proxied here by the CNH one-week interbank rate. To assess statistical significance, the figure shows also a bootstrapped placebo distribution constructed by drawing nine non-overlapping events from other days in the sample. Finally, the blue and red lines show the average

[32]The dates are 26 July 2019, 10 February 2020, 15 February 2021, 29 March 2021, 18 May 2021, 28 June 2021, 17 August 2021, 16 November 2021, and 22 June 2023. We exclude the changes in the stock that arose immediately from the announcements on 20th of June 2019, 8 August 2019 and 6 November 2020. We further exclude rolls offs that were reverted within fewer than five trading days. Finally, we exclude periods when the stock of bills spiked due to a new bill being issued before an old bill maturing.

split between the roll-offs that were reverted in 5 trading days, and those that persisted for longer, respectively (the size of the roll-offs are similar in either case). Therefore, a shock to the quantity of money maps to the textbook shock to interest rates.[33]

At a monthly frequency, these changes in money supply would barely be detectable, as they were reverted by the next auction. Theory suggests that they would have no effect on the exchange rate beyond a few weeks. Policymakers determined to keep the peg at parity would not see this as a problem and, as far as we know, made no adjustments to policy as a response. But, at a daily frequency, these bill roll-offs provide exogenous variation in the supply of money.[34]

Test of the causal effect of money on exchange rates. The left panel of figure 4 shows the average response of the offshore-onshore exchange rate to these monetary expansions (the black line).[35] Proposition 2a) predicts that E should fall, and the estimates confirm this prediction.[36] This effect dies out after around 12 trading days, which corresponds to the average time taken across events for the bill stock to revert to the normal level.

The average exchange rate depreciation of the CNH over a 10-day horizon is 0.11%. Splitting by duration of the monetary expansions, the short-lived ones cause an immediate exchange rate movement of 0.12% that is temporary and rapidly reversed. The longer-lived monetary expansions have a less detectable immediate impact but lead to a larger CNH depreciation that persists beyond 12 trading days.

The right panel shows the response of the offshore-foreign exchange rate $E^{\$}$, which proposition 2c) predicted should rise. The evidence again confirms this prediction. The placebo happens to be declining because the yuan happened to be appreciating relative to the US dollar on average over the sample, making the effect of the shocks more noticeable.

In short, monetarism holds: raising the money supply depreciates the exchange rate.

4.4 The elasticity of money demand

The model makes clear that there are two separate elasticities of money demand: one for the reserves of banks at the central bank, and another for the deposits of households at banks. Combining the prediction in proposition 2b), the empirical estimate that the

[33] A shock to the interest paid on reserves R^m also appreciates the exchange rate, as in the textbook model.

[34] Appendix **??** shows that the anticipation of the changes does not affect the validity of the test.

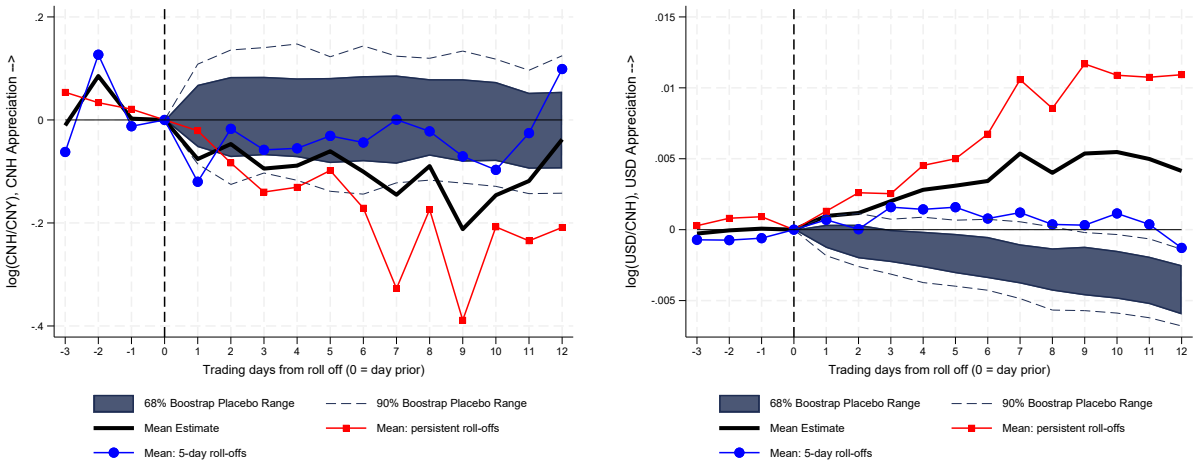
[35] Figure **??** in appendix **??** shows the response after each event.

[36] The data five days before each event does not show clear pre-trends in the exchange rate, from either reversion from other shocks or because of anticipation of the rolloffs.

Figure 4: Exchange rates after an exogenous expansion in the money supply

(a) Response of the CNY-CNH exchange rate to money supply shocks

(b) Response of the CNH-USD exchange rate to money supply shocks



Note: Both panels show 100 times the cumulative change in the log of the daily exchange rate from the trading day prior to the bill roll off, averaged over the events, and bootstrapped placebo intervals from taking 10,000 random samples of an equivalent number of events dates between 1 July 2010 and 1 November 2021, excluding dates that overlap with the original event window and schedule announcements.

exchange rate depreciates 0.11% following an average roll off of ¥11bn of bills, and the average stock of reserves M =¥196bn and deposits D =¥730bn reported in section 2, we get:

$$\varepsilon_m = \frac{11/196}{0.0011} - \left(\frac{196}{730}\right)\varepsilon_d = 51 - 0.27\varepsilon_d. \tag{20}$$

The upper bound for the interest semi-elasticity of demand for reserves of 51 in this expression is well below the cashless-limit assumption of infinity. For comparison, for the United States, Lopez-Salido and Vissing-Jorgensen (2023) estimate it to be 500 during the ample reserve system of 2009-2022, while Afonso et al. (2022) put it at approximately 50 in the early 2009-12 period. With scarce reserves, like in CNH, this should be lower, but since there is also a parallel currency to substitute into, this might make the elasticity higher. This elasticity is central in some of the key discussions of monetary economics: the welfare costs of inflation, the volatility of interest rates and monetary aggregates, and the optimal size of the central bank balance sheet.

A long literature has estimated time-series regressions of the log of the real stock of M1 on the log of the net nominal interest rate on short-term bonds. More recently Benati et al. (2021) reports coefficients across countries that lie between 0.1 and 0.5. Using the

average 1-week CNH wholesale deposit rate of 2.75%, this implies $\varepsilon_d \approx 10$. Then $\varepsilon_m \approx 48$, or that banks are five times more elastic than depositors in their demand for money.

Alternatively, appendix **??** describes a time-series regression of monthly CNH deposits on an aggregate instrument for CNH money demand shocks, described in the next section. This identifies ε_m imperfectly, given the limitation of having data only at a monthly frequency and not controlling for other variables that shift the demand function. Remarkably, the estimate of ε_m is 47, quite close to the estimates above, even though it relies on a different form of variation altogether.

5 The anatomy of the peg

Systematic monetary policy avoids supply shocks and responds to demand shocks for money. A central bank committed to restoring the parity peg wants to follow a rule:

$$\log(M'/M) = \eta \log(E). \tag{21}$$

This captures the classic monetary prescription that, if the currency depreciates, the central bank should cut the money supply. A modern complement is that the central bank should raise its interest rate.

The next proposition lays out the impact of an increase in the demand for money, captured by an unanticipated increase in the parameter μ.

Proposition 3. *Following an increase in the demand for offshore money (μ):*

a) The onshore currency depreciates relative to the offshore currency, E rises. Offsetting it with an increase in offshore money supply brings that exchange rate back towards parity. Therefore $\eta > 0$ ensures that $E\prime < E$.

b) The offshore currency appreciates relative to the foreign currency, so $E^{\$}$ falls. Therefore, the onshore-offshore exchange rate works as an escape valve: an equilibrium percentage change in the relative value of onshore versus foreign currency $\log(\tilde{E}) = \log(E) + \log(E^{\$})$ comes with a larger percentage change in the value of offshore versus foreign currency $\log(E^{\$})$.

c) A complement to depreciating the exchange rate after the shock is to employ liquidity policies that lower the marginal benefit of liquidity $-\phi'(x, \lambda)$ for a given supply of money.

This section interprets each of these three results and tests them by proposing an instrument for shocks to money demand. Since we know from section 1 that the peg has held well, this provides an anatomy of why the peg has held, because of monetary or liquidity policies, and of whether deviations fomr the peg van be interpreted as the current account management described in proposition 1.

5.1 Keeping a peg against money demand shocks

An increase in the demand for offshore deposits μ makes the offshore exchange rate appreciate. Intuitively, it raises the relative value of offshore reserves to provide liquidity, and the banks' portfolio shift from onshore to offshore reserves moves the exchange rate away from the peg. To keep the peg, the central bank can raise the supply of reserves, which brings the exchange rate back to parity.

Why it is hard to test for the monetary policies behind a peg. The correlation between either interest rates or measures of money supply with exchange rates for countries that peg their currency is close to zero in the monthly data.[37] At a monthly frequency, there are too many other shocks and too many deviations from UIP for these correlations to detect this monetary prescription for keeping a peg. Moreover, if the policy is successful, there will be no variation in exchange rates to test its effectiveness in the first place.

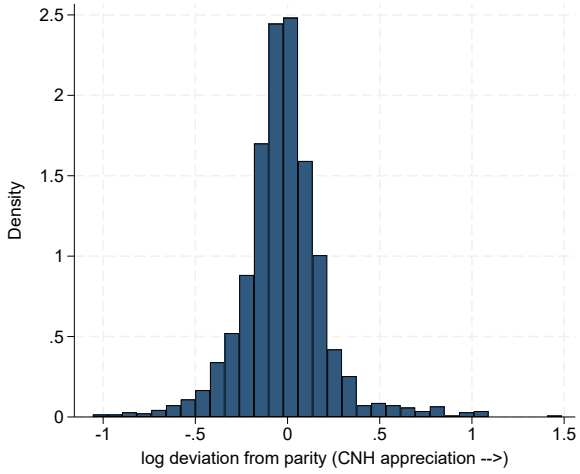
The CNY-CNH testing ground. At a daily frequency, it is challenging for a central bank to perfectly fine tune the money supply whenever the demand for bank deposits happens to change. As a result, the exchange rate deviates from the peg. The central bank can adjust the money supply over the next day(s) so that the deviations of the exchange rate are short lived and the peg is re-established, holding at a lower frequency.

This implies that an appreciation of the exchange rate in one day reflects mostly a positive shock to the relative demand for CNH money. Mostly, because policymakers avoid shocks to money supply; and positive, because the appreciation reflects their inability to accommodate the shock to money demand fast enough. It is a classic result in optimal control theory that in tracking a noisy signal with a (approximately) quadratic loss function, deviations from the objective should be (approximately) normally distributed. The HKMA CNH liquidity system adjusts money supply to track imperfectly-observed shocks to money demand, and the exchange rate measures deviations from this goal. The

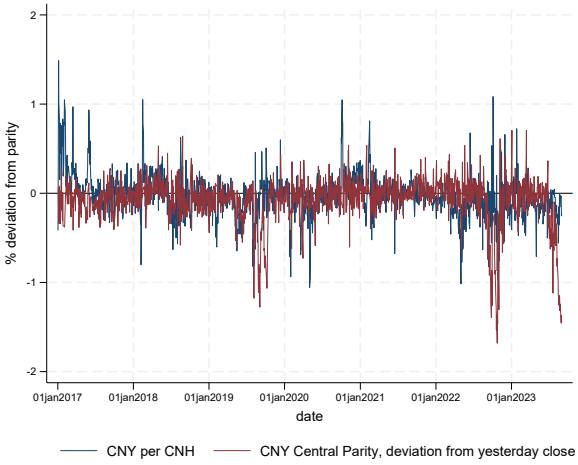
[37] Figure **??** in appendix **??** plots linear regressions between either interest rates or the stock of money, and the exchange rates, for an unbalanced panel of 26 countries that pegged their exchange rate between February 1979 and December 2015. The R^2 of these two regressions are 0.001 and 0.003, respectively.

Figure 5: Movements in the daily exchange rate as shocks to money demand

(a) Histogram of the log daily CNY-CNH exchange rate



(b) CNY-CNH exchange rate and the CNY-USD band deviation instrument



Note: Panel (a) shows the histogram of daily $\log(E_t)$ from April 2017 to August of 2023. Panel (b) shows the log deviation between the CNY-USD central parity band today and the CNY-USD exchange rate yesterday, together with the log of the CNY-CNH exchange rate today.

left panel of figure 5 shows that indeed, deviations from parity are centred around zero with a bell shape. High-frequency movements in E proxy for money demand shocks.

Exogenous drivers of shocks to money demand. After an appreciation of the offshore currency, estimating whether the HKMA raises the supply of money in the next few days provides a monetary anatomy of how the peg is kept. However, insofar as the HKMA is able to adjust the PLP money supply immediately within the day, or there are other supply driven factors influencing the exchange rate, then these estimates would understate the strength of the response of the money supply to the exchange rate.[38]

We use an instrumental variable approach to correct for this downward bias in estimating η. Section 2 explained that the PBoC sets a central parity rate $\bar{E}$ for the CNY-USD exchange rate at the start of the day and allows $\tilde{E}$ to vary in a band of plus and minus 2%. When the CNY is depreciating quickly and the band is close to binding, the escape valve result says that the offshore currency appreciates relative the onshore one, or that E rises. Since a good proxy for the band binding is whether the central parity rate tracked the previous close, then the deviation of the CNY-USD exchange rate today from the central parity rate tomorrow, $\log \bar{E}'/\tilde{E}$, is an instrument for the proportional change in the

[38] Figure **??** in appendix **??** confirms that PLP volumes respond during the day

CNY-CNH exchange rate between today and tomorrow, $\log E'/E = \Delta \log(E_{t+1})$.

The instrument is a function of developments onshore and in the rest of the world, rather than monetary conditions offshore. Moreover since $\bar{E}$ is set in the morning, it is not contaminated by within-day PLP adjustments.[39] The right panel of figure 5 verifies that the two variables are strongly related: the F-statistic for the instrument is 20.

Test of the monetary prescription behind a peg. We estimate the local projection:

$$z_{t+h} = \alpha_h + \beta_h \Delta \log(E_t) + \gamma_h \log(E_{t-1}) + \delta_h z_{t-1} + \text{controls}_{t-1} + \text{error}_t^h, \qquad (22)$$

where z_{t+h} are drawings from the PLP liquidity facility h days after the money demand shock proxied by the movement in E_t and $controls_{t-1}$ that include drawings from the HKMA's discount window facility and overnight and 1-week CNY and CNH interbank rates. The estimates of β_h are measures of the policy rule coefficient η at different horizons. If the estimates are positive, this confirms proposition 3a).

Figure 6 shows that both least squares and instrumental variables estimates are positive and statistically significant. Moreover, as we expected, the IV results are significantly larger. After a money demand shock that causes the offshore currency to appreciate by 1%, the HKMA's supply of money through the PLP rises by approximately ¥5bn to re-establish the peg, or a 2.6% increase in the money supply. Therefore, our estimate of the policy rule is $\eta = 0.026 > 0$.

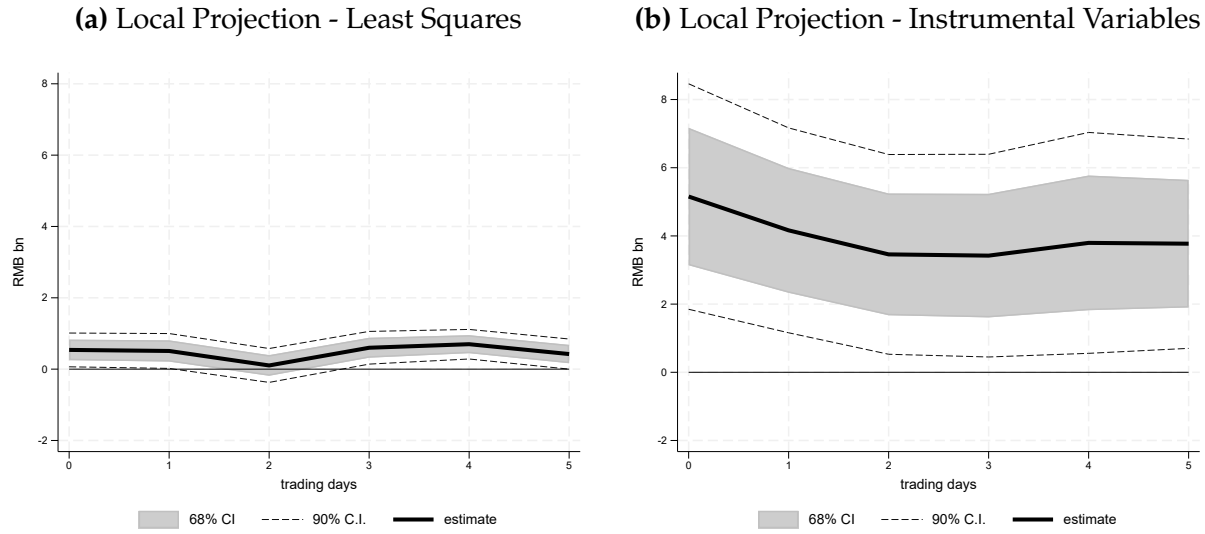
5.2 The offshore market escape valve for the foreign exchange rate

After a money demand shock, the central bank could reestablish the peg quickly by aggressively changing the money supply (a large enough η). The left panel of figure 7 estimates the same local projection as in equation (22) but now using the exchange rate on the left-hand side. The impulse response declines slowly, with a half-life of three days. After 5 days, 0.17 percentage points of depreciation are still missing to get back to parity.

Proposition 3b) gives a reason for why policy only delivers an incomplete adjustment towards $E' = 1$. By not fully responding to the shocks, the central bank can use the onshore-offshore exchange rate to attenuate their impact on the onshore-foreign exchange rate. Intuitively, an increase in the demand for offshore deposits would, all else equal, raise the interest rate on deposits. Foreigners, seeing these higher returns abroad push

[39] The central parity rate is announced at 11am, but considering PLP drawings only between 11am and end of day yields similar results; see figure **??** in appendix **??**.

Figure 6: Response of the HKMA's PLP money supply to a money demand shock



Note: Estimates of equation (22) for PLP drawings. The sample includes all trading days between April 2017 and August 2023. The confidence intervals use White robust standard errors, following Montiel Olea and Plagborg-Moller (2021). Panel (a) estimates the equation using least squares, whereas panel (b) does so using as an instrument the deviation of the CNY/USD exchange rate from the trading band limit.

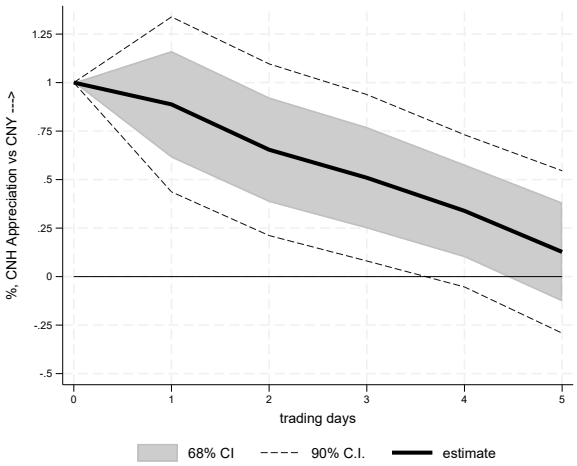
the domestic exchange rate to appreciate up to the point where it is expected to depreciate, re-equating returns across borders. At the same time, the banks that supply these offshore deposits will increase their demand for reserves. If the central bank only partially satisfies this higher demand, then the offshore exchange rate will appreciate. Because it is expected to depreciate, back to its peg, domestic depositors are less willing to demand deposits. This lowers the pressure on the interest rate on deposits, and therefore reduces the adjustment of the domestic exchange rate.

In the case of the yuan, the PBoC has an explicit desire to smooth fluctuations in $\tilde{E}$, the onshore-foreign exchange rate. Having the onshore-offshore exchange rate E deviate from parity gives it a tool to do so. This offshore escape valve is subject to the limit that E cannot fall too far for too long from parity without putting pressure on the capital controls or falling foul of Gresham's Law. But, as a policy tool to absorb transitory fluctuations or smooth permanent adjustments, this can be valuable.

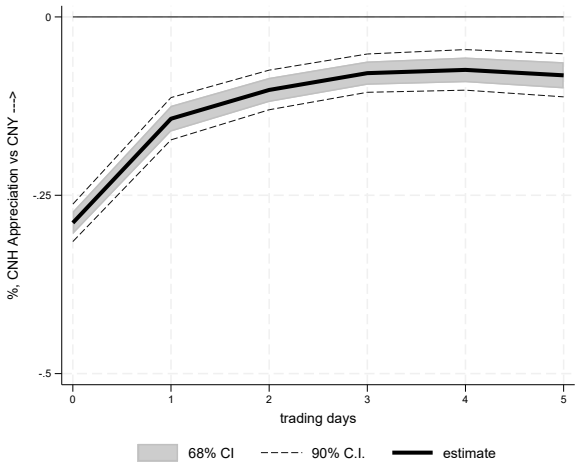
The right panel of figure 7 confirms that it is so by plotting the conditional correlation between $\log(E)$ and $\log(E^{\$})$. At all horizons, this is negative. In line with Proposition 3b), the two exchange rates move in opposite directions, reducing the volatility of their sum. Unconditionally, across all shocks, the empirical correlation correlation of $\hat{E}$ with E

Figure 7: Dynamics of the two exchange rates

(a) CNY-CNH exchange rate after an expansion in money demand



(b) CNY-CNH exchange rate after a rise in the CNH-USD exchange rate



Note: Panel (a) shows estimates of equation (22) replacing z_t with $\log(E_{t+h})$, dropping the corresponding control, and instrumenting with our exogenous shift of money demand shocks. Panel (b) estimates the same local projection without an instrumental variable replacing $\Delta \log(E_t)$ with $\Delta \log(E_t^{\$})$ and adding $\log(E_{t-1}^{\$})$ to the control set. In both panels, the confidence intervals use White robust standard errors, following Montiel Olea and Plagborg-Moller (2021). The sample goes between April 2017 and August 2023.

between April 2017 and August 2023 was -0.19.

More generally, imagine that the onshore currency is, for whatever fundamental reasons, depreciating relative to the foreign currency. If the offshore currency is worth less than parity, then, mathematically, the relevant onshore currency must have depreciated less than it would have otherwise. The onshore-offshore exchange rate serves as an escape valve against these forces for a depreciation.

5.3 The role of liquidity policies

Five days after the shock that appreciated the exchange rate by 1%, it had depreciated back by 0.83% (figure 7a). In the model, following proposition 3c), this can be explained by: (i) the demand shock dissipating or $E^{\$}$ adjusting; (ii) *monetary policies* that expand the money supply either its target (by the PBoC in bills' auctions) or elastically to accommodate demand (by the HKMA in the PLP); and (iii) a shift in the liquidity function that reduces the marginal benefit of liquidity $-\phi'(M/D)$, which we refer to as *liquidity policies*.

On (i), the estimated dynamic correlation of the instrument for demand shocks sug-

gests that, after 5 days, 0.53% of the depreciation is accounted for by the transitory nature of these shocks. To measure (ii), the estimated response of the money supply in figure 6 was ¥5bn. The estimates in section 4.4 of the potency of monetary policy were that each billion depreciated the exchange rate by 0.01%. Therefore, the monetary forces to re-establish the peg contributed a 0.05% depreciation. That leaves as a residual for (iii) that $1 - 0.05/(0.83 - 0.53) = 5/6$ths of the observed average depreciation brought about by policies is explained by liquidity policies. The next section unpacks this residual, decomposing it into shocks and policies, and presenting direct evidence from the CNH experience of its contribution to sustaining the peg to parity.

6 Identifying the liquidity policies

We start in section 6.1 with the Bianchi and Bigio (2022) microfoundation of the liquidity cost function $\phi(.)$ adapted to our setting, before expanding it in the following sections to deliver empirical predictions and consider a broader set of policies.

6.1 A model of the liquidity cost function

During the period, each bank faces a change in its offshore deposits, to which it responds by adjusting its liquid reserves.

Withdrawal shocks. A bank is indexed by ω, an idiosyncratic shock standing for the fraction of start-of-period offshore deposits that are withdrawn by the end of the period. If $\omega = -1$ all of its deposits leave, whereas if $\omega = 0$ none do. Since one bank's outflow are another bank's inflows, some banks receive net inflows $\omega > 0$. At the start of the period, ω is a random variable with support $[-1, \infty)$ and distribution $\Omega(\omega)$ that satisfies:

$$\mathbb{E}(\omega) = \int_{-1}^{\infty} \omega d\Omega(\omega) = 0. \tag{23}$$

Reserve requirements and commitments. By the end of the day, banks must honor all withdrawal requests by settling them one-for-one with reserves in order to stay in business. They must also satisfy at all times a requirement that reserves are at least as large as a share ρ of the deposits.

Liquidity position after the shocks. At the start of the period, the bank's liquidity was the excess of reserves over the requirement: $m - \rho d$. After withdrawals, liquidity

increases by the inflow of deposits in excess of the reserve requirement: $\omega d(1-\rho)$. Its net surplus of liquidity after a shock is:

$$s(\omega) = m - \rho d + \omega d\,(1-\rho)\,. \tag{24}$$

This defines a liquidity threshold, $\bar{\omega}$ such that:

$$s(\bar{\omega}) = 0 \quad \Leftrightarrow \quad \bar{\omega} = \frac{\rho - \frac{m}{d}}{1-\rho}. \tag{25}$$

Banks with $\omega < \bar{\omega}$ will have a liquidity deficit. Those above it, have a liquidity surplus during the period. Naturally, the higher the reserve-deposit ratio m/d, the less likely it finds itself in a deficit as the threshold $\bar{\omega}$ is lower.

Interbank market tightness. Banks with liquidity surpluses and deficits try to meet each other in an over-the-counter interbank market to lend and borrow offshore reserves. They must search for each other and tightness in this market θ is the ratio of the aggregate demand for liquidity to its aggregate supply:

$$\theta = \frac{-\int_{-1}^{\bar{\omega}} s(\omega) d\Omega(\omega)}{\int_{\bar{\omega}}^{\infty} s(\omega) d\Omega(\omega)}, \tag{26}$$

which clearly falls with $\bar{\omega}$. Each individual bank takes the market tightness as given.

Search and bargaining in the interbank market. A bank with a liquidity deficit finds a bank with a surplus with probability $\Psi_-(\theta)$, that we assume falls in θ; a lender bank matches with a borrower with probability $\Psi_+(\theta)$ that rises with θ. If a borrower fails to find a lender (or does not agree on terms) it can borrow at the central bank's discount window facility at a given rate R^z.

In the interbank market, a lender and borrower that meet will bargain over the interbank interest rate $R^f(\theta)$. Since the outside opportunity of the lender is to earn the interest on reserves R^m, while that of the borrower is to go to the discount window at rate R^z, the function $R^f(\theta)$ has domain $[R^m, R^z]$, and we assume only that it is increasing in θ.

The liquidity cost function. Combining all the ingredients, if the bank finds itself in a surplus, because $\omega > \bar{\omega}$, it will find someone to lend to with probability $\Psi_+(\theta)$ and earn a profit of $R^f(\theta) - R^m$ per unit of reserves lent. Instead, if $\omega < \bar{\omega}$, it will have to cover its deficit by borrowing in the interbank market at cost per reserve of $R^f(\theta) - R^m$.

With probability $1 - \Psi_-(\theta)$, the bank does not find a lender and must borrow from the discount window at the higher cost $R^z - R^m$. Expected liquidity costs are:[40]

$$\phi(m/d)d = - \underbrace{\Psi_+(\theta)}_{\text{prob. find borrower}} \times \underbrace{(R^f(\theta) - R^m)}_{\text{lending profit}} \times \underbrace{\int_{\bar{\omega}}^{\infty} s(\omega) d\Omega(\omega)}_{\text{liquidity surpluses}}$$
$$- \left[\underbrace{\Psi_-(\theta)(R^f(\theta) - R^m)}_{\text{interbank borrowing}} + \underbrace{(1 - \Psi_-(\theta))(R^z - R^m)}_{\text{CB borrowing}} \right] \underbrace{\int_{-1}^{\bar{\omega}} s(\omega) d\Omega(\omega)}_{\text{liquidity deficits}}. \quad (27)$$

In section **??** we assumed properties of the $\phi(m/d, \lambda)$ function that we can now verify against its micro-foundation: it depends on the ratio m/d; it is bounded below by 0 and above by $R^z - R^m$ and in turn by m; and at the top of the domain $\phi(1) = 0$.

The liquidity policies. The model clarifies what are the liquidity policies λ that the reduced-form model took as given.

The first of these are onshore reserve requirement ρ. An increase in this policy variable raises the cost of not having enough liquidity.

The second is the price of liquidity captured by the discount window rate R^z. If the central bank makes it harder to over withdrawls, the expecdted costs of supplying deposits for a gives amount of reserves is higher.

The third is the efficiency of matching in the offshore interbank market, which will be captured by the function $R^f(\theta)$. Different regulations that affect this market will raise the bargained interbank rate and make liquidity sahortfalls more expensive.

6.2 Liquidity variables after a money demand shock

Appendix **??** proves the following result:

Proposition 4. *The marginal benefit of liquidity evaluated at the equilibrium reserve-deposit ratio is:*

$$-\phi'(M/D) = (1 - \Psi_-(\theta))(R^z - R^m)\Omega(\bar{\omega}). \quad (28)$$

A rise in money demand that is only partially offset by a rise in money supply (E rises) leads to:

a) an increase in the tightness in the interbank market θ;

[40] Since reserves yield R^m but deposits pay R^d settling reserves for deposits one-for-one incurs a cost due to the interest differential. However, this nets out in expectation when $\mathbb{E}[\omega] = 0$.

Table 2: Regression of bill auction subscription rate on the exchange rate

Bill maturities	All	12M	6M	3M
	(1)	(2)	(3)	(4)
$\frac{1}{5}\sum_0^4 \log(E_{t-h})$	-2.76***	-3.38***	-2.78***	-3.38***
	(0.93)	(1.10)	(0.93)	(1.12)
Number of Auctions	35	19	16	19
R^2	0.142	0.335	0.131	0.324

Heteroskedasticity robust standard errors in parentheses

* $p < 0.1$, ** $p < 0.05$, ***$p < 0.01$

Note: The sample has 56 issuance of bills in 35 different auctions between November 2018 and May 2023. In 19 of these auctions, the PBoC issues 3M and 12M maturities, while in the other 16 auctions it issued the 6M maturity. The subscription rate is defined as bids divided by bills auctioned. Column (1) considers the subscription rate across all maturities at the auctions date, and columns (2)-(4) each maturity separately. Columns (2) and (4) are estimated in a seemingly unrelated regressions to account for the fact the 3M and 12M subscriptions occur simultaneously.

b) an increase in the interbank rate $R^f(\theta)$;

c) greater use of the discount window liquidity facilities.

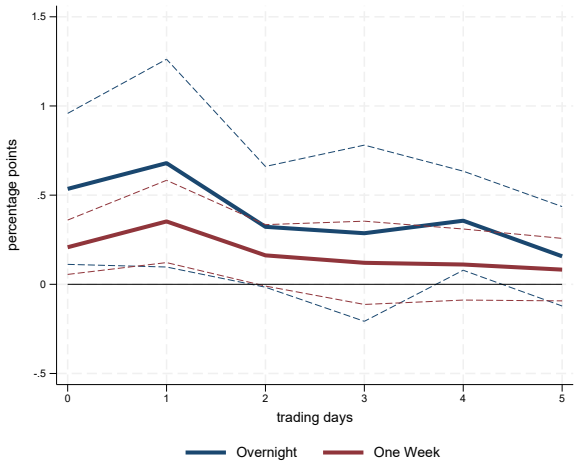
This proposition translates the shift in the marginal benefit of liquidity into three endogenous liquidity variables. We already identified at the end of section 5 a shift in $-\phi'(x, \lambda)$ following a shock to money demand as a residual in the adjustment of the exchange rate. This allows us to test the key channel through which liquidity policies would work.

Tightness and bills auctions. Empirically, prediction a) would show up in a decline in the bid rate for CNH bills by banks. Intuitively, the missing supply of HKMA money means banks are less willing to hand CNH reserves to the PBoC in exchange for bills. As we discussed before, the PBoC runs regular auctions for bills at a lower frequency than the HKMA can act. Between the PBoC announcing an auction and taking bids, on average 6 trading days go by, so at high frequency, the quantity of bills supplied does not respond to the demand for money. An appreciation of offshore currency, reflecting a rise in demand for CNH money, will lower demand for bills.

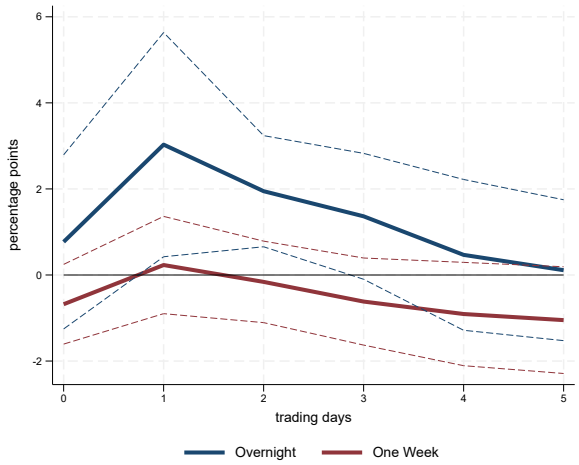
Table 2 tests this negative effect by regressing the subscription rate on the average deviation from the peg in the five days prior to the auction to capture the interval after an

Figure 8: Interbank rate response to a money demand shock

(a) Local Projection - Least Squares



(b) Local Projection - Instrumental Variables



Note: Estimates of equation (22) for the overnight and one-week CNH interbank interest rate. The sample period is all trading days between April 2017 and August 2023. Confidence intervals use White heteroskedasticity robust standard errors, following Montiel Olea and Plagborg-Moller (2021). Panel (a) estimates the equation using least squares, whereas panel (b) does so using as an instrument the deviation of the CNY/USD exchange rate from the trading band limit.

auction is announced and before it takes place. The estimated coefficients are negative.[41]

Interest rates. Prediction 4b) is that, when the overall money demand rises, banks needing liquidity will turn to borrowing from other banks that have a liquidity surplus. This increase in demand in the interbank market raises the private-market price for liquidity.

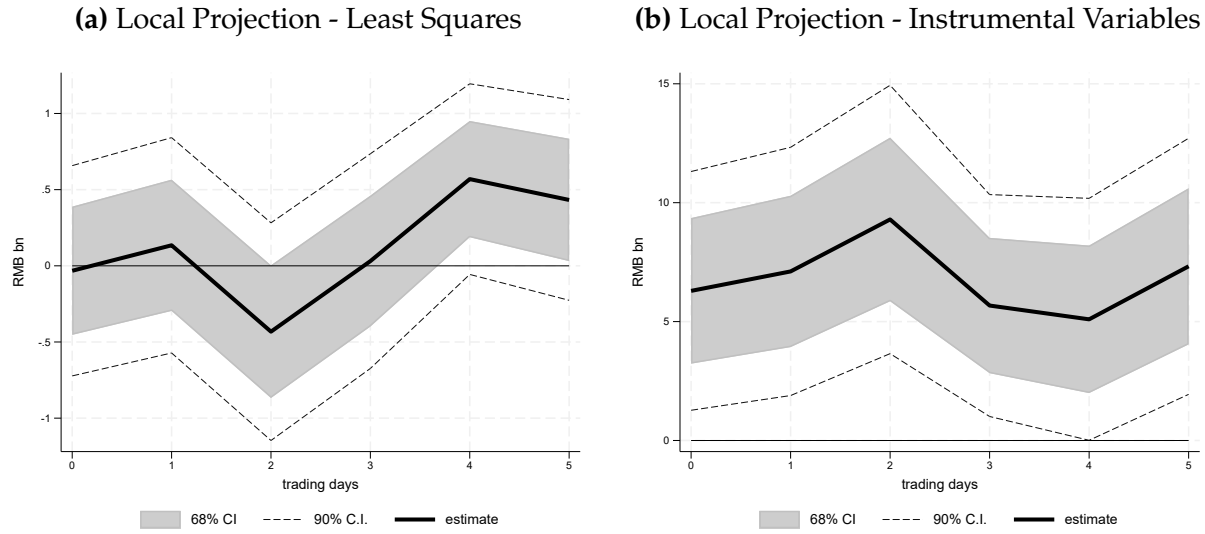
In the data, the substitute for HKMA PLP balances is the interbank money market. Figure 8 estimates the same local projection as in equation (22), but with the overnight and one-week CNH interbank rate on the left-hand side. The least-squares estimates confirm the theory prediction that the rate rises. The effects are larger with the IV estimates on the right panel (note the change in the scale) but only at the overnight maturity.

Discount window borrowing. The third and final prediction in the proposition arises because the money demand shock lowers the deficit threshold $\bar{\omega}$. With more demand for money, a bank is more likely to be in a liquidity deficit, not find a lender with probability $1 - \Psi_{-}(\theta)$, and go to the discount window.

In the case of CNY-CNH, by keeping the money supply scarce, the PBoC ensures that

[41] Table **??** in appendix **??** uses instead the exchange rate on the day of the auction. Because the auction results are only announced after the market closes, and the bills are settled two days later, they do not contaminate the exchange rate. The effect is less precisely estimated and weaker, but the conclusion holds.

Figure 9: Response of HKMA discount window borrowing to a money demand shock



Note: Estimates of equation (22) for the liquidity facility drawings. The sample has all trading days between April 2017 and July 22nd 2022 when the terms on the HKMA lending facilities changed. The confidence intervals use White robust standard errors, following Montiel Olea and Plagborg-Moller (2021). Panel (a) estimates the equation using least squares, whereas panel (b) does so using as an instrument the deviation of the CNY-USD exchange rate from the trading band limit.

on aggregate banks find themselves routinely having to take this route. Figure 9 shows estimates of the same regression as in equation (22), but now with drawings from the liquidity facilities as the measures of z_{t+h}.[42] The increase in money demand generates a rise in discount window borrowing of around ¥6bn.[43]

6.3 Further shocks to test the liqudity channels

Shocks to the marginal benefit of reserves put pressure on the peg. Conversely, liquidity policies that steer the marginal benefit of reserves can contribute to sustaining the peg and managing the escape valve. The next result identifies some of these shocks and policies in order top look for further evidence of the liquidity channel.

Proposition 5. *The marginal benefit of liquidity rises when:*

a) the financial markets deteriorate: $\Psi_{-}(\theta)$ *falls or* $\Omega(.)$ *shifts up;*

[42]The results in figure 9 use only the intraday facility. Using the sum across the two facilities leads to almost identical results. The sample ends in July 2022 because of a reform that we will discuss next.

[43]Figure **??** in appendix **??** splits the impact between different times of the day. The use of the discount window rises as soon as the market opens and persists during the day.

b) reserve requirements are higher: ρ is higher, which raises $\bar{\omega}$;

c) the costs of emergency borrowing from the central bank is higher: R^z rises.

The first prediction points to another source of shocks to the peg: financial innovation. A higher $\Psi_-(\theta)$ may be due to an increase in the efficiency of matching in the interbank market. A shift down of $\Omega(.)$ can arise from banks being better able to either retain depositors or to predict withdrawals. Either of them lowers the marginal benefit of reserves, depreciates the onshore-offshore exchange rate, and puts pressure on the peg.

Empirically, these shocks would show up as large fluctuations in the reserve-deposit ratio seemingly breaking the relation between monetary aggregates and the exchange rate (Goodhart's law). A plot of bank deposits in CNH relative to deposits in CNY on the lagged exchange rate using monthly data between April 2017 and April 2023 in figure **??** in appendix **??** reveals a relation with an R^2 of just 0.04.

The second prediction states that raising reserve requirements will make it more likely that banks will find themselves scrambling for reserves. Therefore, it raises the marginal benefit of having reserves, and so pushes E up. Historically, central banks have changed reserve requirements in response to financial innovation that shifts the money multiplier. According to media reports, the PBoC does too, sometimes in the form of foreign risk reserve ratios, sometimes through other regulations and moral suasion. Yet, we have no direct empirical evidence to test it.

The third prediction notes that if the central bank makes its backstop liquidity more expensive, this will raise the marginal benefit of holding on to reserves beforehand. In the case of the CNH, the HKMA could do this by raising the rate it charges on its liquidity facilities, by lowering its own CNH reserves to lower the threshold at which it would have to resort to the swap line with the PBoC, or by raising the rate on that line. We have evidence to test this last prediction.

Evidence from two HKMA reforms. Initially, when the HKMA intraday lending facilities started, banks could borrow paying a rate of 50bp above the previous day's overnight interbank rate. On the 5th of April of 2016, the HKMA changed the lending rate to 50bp plus the average of the previous three days' overnight rates.

We estimate the following autoregressive distributed lag regression on a sample from the 4th of November of 2015 to the 1st of September of 2023, with a dummy variable $Post_t$ that takes the value one for observations after the 5th of April of 2016, and controlling for three lags of $\log(E_t)$, the onshore overnight rate, and the offshore and onshore three-

month rates (in parentheses are Newey-West standard errors):

$$\begin{aligned}\log(E_t) = &\underbrace{-0.04}_{(0.23)} R^f_{t-1} - \underbrace{0.62^{***}}_{(0.23)} R^f_{t-2} - \underbrace{0.51^{***}}_{(0.12)} R^f_{t-3} - \underbrace{0.01}_{(0.17)} R^f_{t-4} \\ &+ Post_t \times (\underbrace{0.57^{**}}_{(0.28)} R^f_{t-1} - \underbrace{0.52}_{(0.37)} \times R^f_{t-2} + \underbrace{\mathbf{1.25^{***}}}_{\mathbf{(0.29)}} \times \boldsymbol{R^f_{t-3}} + \underbrace{0.15}_{(0.27)} \times R^f_{t-4}) \\ &+ \text{controls}_t + \text{error}_t. \end{aligned} \tag{29}$$

The key coefficient, in bold, is statistically significantly and positive. This says that, after the reform, ceteris paribus, a higher overnight rate three days ago is now associated with an appreciation of the CNH. Consistent with the model, once this lagged rate became an indicator for the cost of lending from the discount window, then a higher rate meant that emergency liquidity became more expensive. The ex ante marginal benefit of reserves was higher, and the relative value of the offshore currency rose.

On the 22nd of July of 2022 the HKMA announced a second reform and implemented it on the 27th. The HKMA cut the premium on lending from 50bp to 25bp, and raised the maximum quantity banks could borrow from ¥10bn to ¥20bn. By lowering the costs of emergency liquidity, this reform lowers the marginal benefit of reserves. Therefore, it should depreciate the value of the offshore currency and lower the difference between onshore and offshore overnight rates. Indeed, in the ten trading days after the new regime was in place, relative to the average in the ten trading days before, $\log(E)$ was on average 1.7bp lower and the interest rate differential was 10bp lower.

6.4 More liquidity policies

this section extends the model to introduce three more liquidity policies.

Extended model. In the model so far, increases in reserves M are helicopter drops of money. In reality, central banks increase M by purchasing government bonds or central bank bills, just as the PBoC does. Let G be the stock of central bank bills. We introduce them in the model by assuming that bills can be sold frictionlessly to obtain reserves, but only reserves can be used to settle meet withdrawals (and the interbank market is for reserves only). Second, we now allow banks to move onshore reserves to offshore reserves to lend in the interbank market. We denote this inflow of liquidity by W^m, and assume that it is exogenous because the PBoC has a tight control over the clearing banks through which these transfers happen. Third and finally, we allow offshore depositors

that withdraw to move their funds to the onshore market and vice versa, instead of having to deposit them in another onshore bank. The mean of the distribution of withdrawals $\Omega(\omega, W^d)$ is no longer zero but rather equals this deposit flow W^d. Given the capital controls, we treat W^d as a policy tool of the central bank.

Appendix **??** lays out the model and shows that interbank market tightness is now:

$$\theta = \frac{-\int_{-1}^{\bar{\omega}} s(\omega) d\Omega(\omega; W^d)}{\int_{\bar{\omega}}^{\infty} s(\omega) d\Omega(\omega, W^d) - G + W^m}. \tag{30}$$

This leads to the following result proven in appendix **??**:

Proposition 6. *With central bank bills (G) and exogenous constraints on reserve flows (W^m) and deposit flows (W^d) in the model for liquidity, the following policies raise tightness θ, the marginal benefit of reserves $-\phi'(M/D)$, and the exchange rate E:*

a) a cut in reserves that is paid for by issuing bills, so M falls but $M + G$ is unchanged;

b) a tightening of the restriction in reserve flows W^m;

c) a tightening of the restriction in deposit flows W^d.

Intuitively, a cut in the money supply that injects bills has no effect on the threshold for being in a liquidity deficit, $\bar{\omega}$, since banks can still meet withdrawals with their bills. However, now the interbank market is tighter, as there are fewer reserves for banks to offer there. This is why G appears in the denominator in equation (15) and so swapping M for G raises the marginal benefit of reserves. A cut in W^m works just in the same way, by making the interbank market for reserves tighter. Finally, a cut in W^d shifts left the distribution $\Omega(\omega)$ since it makes it more likely that banks will have a liquidity deficit.

Evidence from the 2015–16 financial crisis. In 2015–16, macro-financial forces led to a trend depreciation of the yuan relative to the dollar visible in panel (a) of figure 10. Initially, the PBoC held the central parity rate, $\bar{E}$ relatively constant. The CNY/USD exchange rate persistently traded at the lower bound of the trading band. In August of 2015, the PBoC switched to fixing the parity rate near the previous day's close. This prompted a 3% depreciation in the CNY between August 11th and 13th, marked with the first vertical dashed blue line in figure 10. As predicted by the model, given its role as an escape valve, the CNH depreciated one additional percentage point against the USD. The CNH traded at an average 0.6% discount relative to CNY throughout the remainder of 2015.

The PBoC's response in December 2015 was to tighten the liquidity controls on the flow of deposits and reserves (W^d and W^m in our model). Panel (b) shows the sharp fall in the flows from the onshore to the offshore market in the Chinese current account, more than one fifth right away, and a further two fifths over the next few months.[44]

Panels (c) and (d) show the consequences for liquidity, which line up with our model and the identified empirical mechanisms. Panel (c) shows that the stock of CNH deposits (D in our model) fell by 20 log points relative to CNY deposits during the December 2015 tightening. Panel (d) shows that the PBoC's actions caused the 3-month CNH interbank rates ($R^f(\theta)$ in the model) to spike above 10%, while equivalent CNY rates were stable at around 3%, again as predicted by our model as a result of increased tightness in the interbank market (θ). This intervention brought CNY-CNH closer to parity but the scarcity of CNH meant that the internationalisation of the RMB paused.

Over the course of 2016, the CNY remained on a depreciating trend, and the CNH successively traded below parity (panel (a)). When depreciation intensified at the end of the year, the PBoC repeated its intervention in December 2016. Again, liquidity controls were tightened (panel (b)), CNH deposits fell by 40 log points on a relative basis (panel (c)), and interbank rates leapt (panel (d)), bringing about a sharp appreciation of CNY-CNH that pushed it above parity (panels (a) and (c)). This ended at the start of 2017, partly helped by the stabilisation of the exchange rate with the USD, partly by setting up the framework described in section 2.

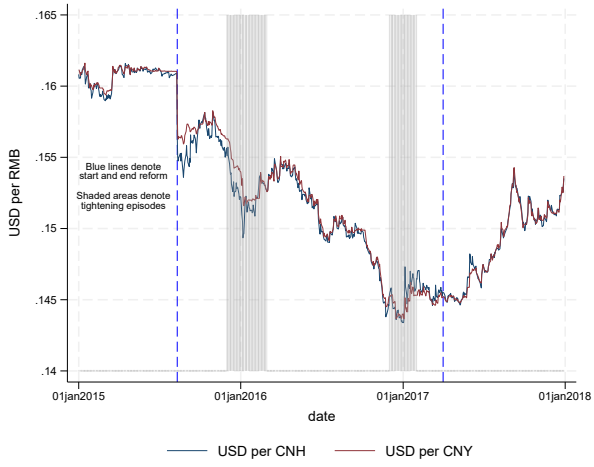
Evidence from the August 2023 devaluation. In the spring of 2017, the PBoC introduced a countercyclical factor in the central parity band and created the regular auctions of bills giving it greater control over the offshore money supply. Also, during 2016 and 2017, the HKMA reformed the automatic liquidity facilities, expanding the number of primary liquidity providers from 7 to 9, lowering the penalty rates on the discount windows, and expanding the set eligible collateral. The data since April 2017 has seen the CNY-CNH exchange rate much closer to parity, in spite of large fluctuations in the exchange rate with the USD (recall figure 1). This system was tested in the summer of 2023, when again the yuan depreciated relative to the dollar.

Figure 11 shows the financial variables during this time. Panel (a) shows the steady depreciation of the yuan, and panel (b) shows that again CNH started trading below parity relative to CNY. Panels (c) and (d) show the automatic responses to this negative money demand shock: the interbank rate in CNH spiked relative to CNY, and borrowing

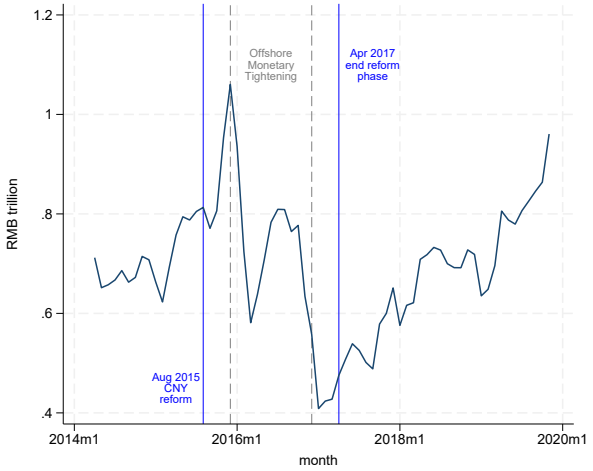
[44]The flows in the other direction are reported in appendix figure **??**.

Figure 10: The monetary tightenings of 2015 and 2016

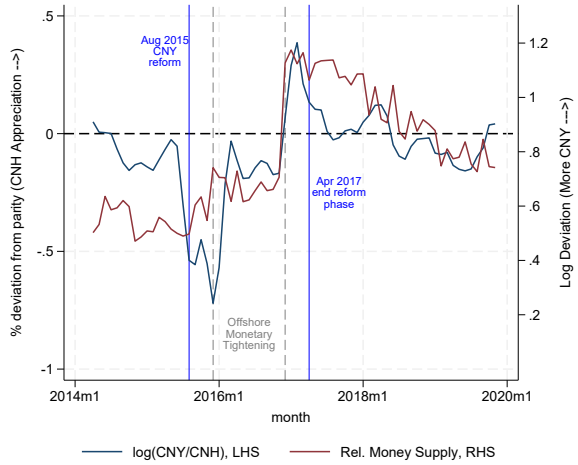
(a) CNH/USD and CNY/USD exchange rates



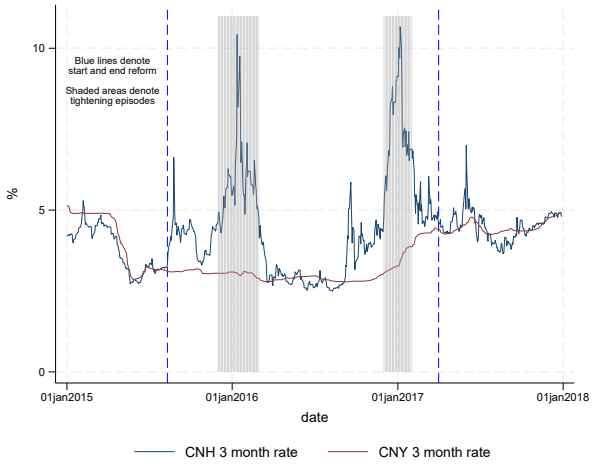
(b) RMB flows from onshore to offshore



(c) Relative CNY-CNH deposit stock and $\log(E)$



(d) 3-month interbank rates for CNY and CNH



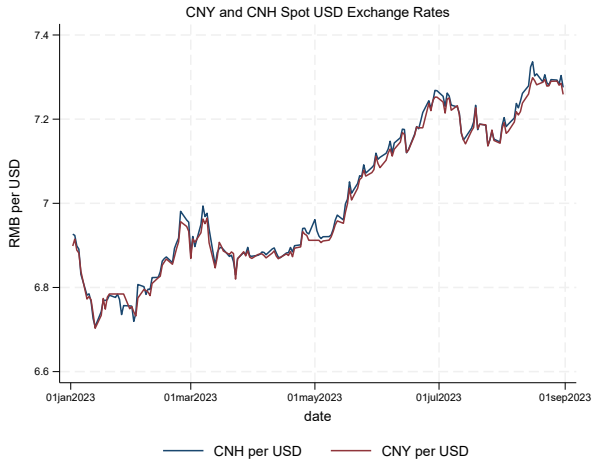
Note: Panel (a) shows yuan exchange rates. Panel (b) shows the conversion of CNH into CNY from the current account, at a monthly frequency. Panel (c) shows $\log(D_t^{\text{CNY}}) - \log(D_t^{\text{CNH}})$ against monthly average $\log(E_t)$. Panel (d) shows yuan interbank rates.

from the liquidity facility at the HKMA increased. Also, the amount bid for CNH bills increased by 50% in the August auction relative to the May auction.

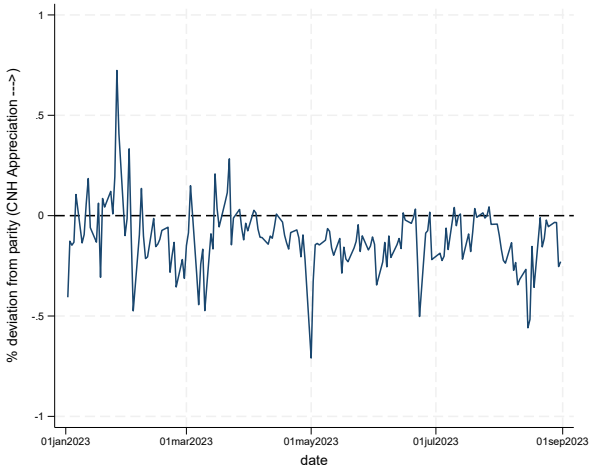
This time, the PBoC did not resort to draconian liquidity controls, and there was no crash in financial markets or damage to the growth of the yuan as an international currency. Instead, the PBoC responded by increasing the issuance of CNH 3M bills from ¥10bn to ¥20bn in the August auction, reducing the money supply. State banks sold USD reserves in a way similar to a sterilised foreign exchange market intervention, and

Figure 11: The August 2023 episode

(a) CNH-USD and CNY-USD exchange rates



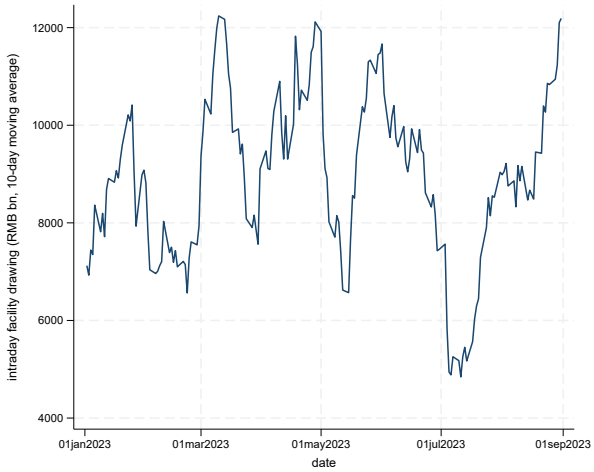
(b) CNY-CNH exchange rate



(c) 3-month interbank rates for CNY and CNH



(d) HKMA discount window borrowing



Note: The sample is all trading days between 1 January 2023 and 31 August 2023. Panel (a) shows CNY-USD and CNH-USD exchange rates. Panel (b) shows $100\log(E)$ so an increases is a CNH appreciation. Panel (c) shows CNY and CNH interbank rates. Panel (d) shows the 10-day moving average of maximum daily drawings from the HKMA's intraday RMB liquidity facility.

changed their holdings of CNH, which is akin to a helicopter drop. In the language of the model, the PBoC cut M, but also employed liquidity policies to raise $-\phi'(M/D)$. These policies complemented the movement in E shown in the figure, in order to prevent $E^{\$}$ moving as much as it would have otherwise. With the post-2017 framework that we analysed in this paper, the stress in the peg was smaller, with less of an increase in interbank rates and smaller and less persistent deviations from the peg.

7 Conclusion

More than fifteen years ago, Chinese monetary authorities created an offshore currency that could be used freely for foreign transactions, while imposing strict controls in the exchange of this offshore currency for its onshore counterpart. This was set up to enforce capital controls, while at the same time allowing for an open current account and for the yuan to be used as an international currency. It created a regime of parallel currencies, requiring a monetary and liquidity system that kept their exchange rate close to parity.

Institutionally, this paper explained this system. After unpacking its components, it made clear that there are conventional monetary and liquidity forces at play. Therefore, we can use the Chinese experience to understand the classic links between policies and exchange rates. At the same time, the use of this system to promote the internationalisation of the yuan, to enforce capital controls, and to aid in managing the exchange rate with foreign currency and the current account is more novel, and may be useful in other settings.

Empirically, we used this monetary experiment and its peculiarities to put forward some credible evidence on what drives exchange rates. We found that exogenous transitory increases in the money supply depreciate the exchange rate. The implied interest-rate elasticity of the demand for reserves at the central bank is 48, significantly less than the infinity of ample reserve frameworks or cashless-limit theories, but more than the zero of the simple quantity theory.

In the data, monetary policy has responded to increases in the demand for money by raising the money supply. This has kept deviations from the peg small and short-lived, helping to sustain the capital controls, while providing an escape valve when the yuan is depreciating relative to the dollar, helping to sustain the CNY-USD trading band.

We found a large and significant role for liquidity policies complementing monetary policies. Increases in the demand for money reduced the demand for bonds, raised interbank rates, and increased borrowing from the discount window in the data. Reforms to the emergency lending facility affected the exchange rate via the marginal benefit of an extra offshore reserve. Finally, a tightening of liquidity controls offset a large shock, but with severe consequences on liquidity measured by deposits or interbank rates. Altogether, monetary and liquidity policies have prevented the usual demise of parallel currencies and have allowed for interventions to affect the exchange rate and the current account.

Along the way, we revisited some of the fundamental pillars of monetarism: (i) if you

raise the money supply, you will reduce the value of currency; (ii) if you want to peg this value, respond to rises in it by printing money; (iii) liquidity policies to steer money demand must complement control of money supply; (iv) parallel currencies survive by keeping a tight peg between their value. China's "weird" offshore system allowed us to test these and find that with respect to each one: (i) yes, and elasticity of money demand driven by reserves (elasticity of 50); (ii) yes, but only one sixth, with the remaining five sixths achieved by liquidity policies; (iii) yes, and include reserve requirement, discount window rate, liquidity restrictions, and FX internventions, and (iv) yes, and successful if have a whole coherent framework.

The model and empirics combined suggest that the current institutional framework seems to be up to the task. As we showed, many shocks have hit the system, yet deft management of monetary and liquidity policies have preserved the peg. Our analysis provides future guidance for the PBoC on which shocks may burst the seams of its framework and how to reinforce them. More intriguingly, this paper's results suggest that the international use of the yuan could still significantly increase. Also, other countries could try frameworks inspired by this experience. And finally, offshore arrangements can be used to temporarily relax the trilemma complementing foreign exchange interventions.

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